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VALIDATION OF THE STANDARD MOBILITY APPLICATION PROGRAMMING INTERFACE FIDELITY 1 AND 2

July 2006

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U.S. ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY
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13. ABSTRACT (Maximum 200 words)

This report documents the validation of the stand-alone Standard Mobility Application Programming Interface (STNDMob API) at Fidelity 1 and 2, hereafter referred to as the STNDMob. Fidelity 1 and 2 functionality addresses the lower resolution speed prediction capability of STNDMob, Version 3.2.3.0. Future efforts may consider STNDMob's medium resolution speed prediction capability referred to as Fidelity 3 and 4. At the time of this writing, the validation of Fidelity 3 and 4 functionality is not planned. The North Atlantic Treaty Organization Reference Mobility Model II (NRMM) Version 2.7.2 is the standard by which the STNDMob Fidelity 1 and 2 predictions were validated.

The Training and Doctrine Command Analysis Center (TRAC) is the developer of the Combined Arms Analysis Tool for the 21st Century (COMBAT XXI) model. TRAC has designated the U.S. Army Materiel Systems Analysis Activity (AMSAA) as the verification and validation (V&V) agent for the physical algorithms. COMBAT XXI is the Army's next generation Brigade and below combat effectiveness simulation. COMBAT XXI will allow for higher fidelity ground mobility predictions relative to legacy combat effectiveness models. The core element that allows COMBAT XXI to effectively simulate mobility at these higher fidelity levels is the STNDMob. It was determined that a validation of the stand-alone STNDMob prior to its integration with COMBAT XXI was appropriate. The STNDMob is being developed by the U.S. Army Corps of Engineers, Engineer Research and Development Center (ERDC).

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LIST OF ACRONYMS

ACE	Army Corps of Engineers
ATV	All Terrain Vehicle
AMSAA	Army Materiel Systems Analysis Activity
APC	Armored Personnel Carrier
API	Application Programming Interface
AVLB	Armored Vehicle Launched Bridge
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
COMBAT XXI	Combined Arms Analysis Tool for the 21st Century
CRREL	Cold Regions Research and Engineering Laboratory
ERDC	Engineer Research and Development Center
GSL	Geotechnical and Structures Laboratory
HEMTT	Heavy Expanded Mobility Tactical Truck
HEMAT	Heavy Equipment Mobile Ammunition Trailer
HET	Heavy Equipment Transporter
HMMWV	High Mobility Multipurpose Wheeled Vehicle
ICV	Infantry Carrier Vehicle
JSIMS	Joint Simulation System
kph	kilometers per hour
LAV	Light Armored Vehicle
MLRS	Multiple Launch Rocket System
MLU	Mobility Lookup
mph	miles per hour
MTV	Medium Tactical Vehicle
NRMM	North Atlantic Treaty Organization Reference Mobility Model
PLS	Palletized Load System
rms	root-mean-square
STGJ	Surface Trafficability Group, JSIMS Mobility Model
STNDMob API	Standard Mobility Application Programming Interface
VISOBS	Visibility / Obstacles

V&V	Verification and Validation
WARSIM	Warfighters' Simulation
XML	Extensible Markup Language

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VALIDATION OF THE STANDARD MOBILITY APPLICATION PROGRAMMING INTERFACE FIDELITY 1 AND 2

1. INTRODUCTION

This report documents the validation of the stand-alone Standard Mobility Application Programming Interface (STNDMob API) at Fidelity 1 and 2, Version 3.2.3.0, hereafter referred to as the STNDMob. Fidelity 1 and 2 functionality addresses the lower resolution speed prediction capability of STNDMob. Future efforts may consider STNDMob's medium resolution speed prediction capability referred to as Fidelity 3 and 4. At the time of this writing, the validation of Fidelity 3 and 4 functionality is not planned. The North Atlantic Treaty Organization Reference Mobility Model II (NRMM) Version 2.7.2 is the standard by which the STNDMob Fidelity 1 and 2 predictions were validated. Earlier versions of STNDMob are considered too immature for analytical purposes due to the presence of critical software anomalies.

The Training and Doctrine Command Analysis Center (TRAC) is the developer of the Combined Arms Analysis Tool for the 21st Century (COMBAT XXI) model. TRAC has designated the U.S. Army Materiel Systems Analysis Activity (AMSAA) as the verification and validation (V&V) agent for the physical algorithms. COMBAT XXI is the Army's next generation Brigade and below combat effectiveness simulation. AMSAA's COMBAT XXI V&V team approached the AMSAA Mobility Team regarding the V&V of the COMBAT XXI's mobility prediction mechanism. COMBAT XXI will allow for higher fidelity ground mobility predictions relative to legacy combat effectiveness models. The core element that allows COMBAT XXI to effectively simulate mobility at these higher fidelity levels is the STNDMob. It was determined that a validation of the stand-alone STNDMob prior to its integration with COMBAT XXI was appropriate. The STNDMob is being developed by the U.S. Army Corps of Engineers, Engineer Research and Development Center (ERDC).

This report does <u>not</u> address model accreditation and addresses verification in only a very limited fashion. The User accredits whether the tool is appropriate for any particular application. The User should use this validation as partial input in determining whether the STNDMob Fidelity 1 and 2 is appropriate for their application.

The term validation, and not V&V, is intentionally used throughout this document. Verification is the process of determining that the simulation representation is an accurate implementation of the developer's conceptual description and specification. Validation is the process of determining the degree to which a model reflects the intended real-world entity or process from the perspective of the intended uses of the model. A thorough verification procedure of the STNDMob was not performed as the resources required to conduct such a task were prohibitive. Validation was considered the key element and the decision was made to focus resources in that direction. Some verification procedures were performed to assure that the STNDMob's basic functionality was working as designed. Some examples of verification procedures that are included in this report are assuring that 1) the expected speed values are being selected from the appropriate speed tables, 2) the vehicle files reasonably represent the platforms in question, and 3) the interpolation of speed predictions are accurate. On several occasions, these verification efforts led to code changes that resulted in a more robust software product.

STNDMob performance requirements are study-dependent and are set by the User. The User will need to set performance requirements as part of the accreditation process. The results from this validation may be compared to the User's accreditation requirements, thus allowing the User to determine if the STNDMob can meet their analytical needs. In order to quantify tests related to this validation, benchmarks were set so that the outcomes could be expressed in a meaningful manner. For the majority of cases, ±5 mph with respect to the NRMM benchmark was used (e.g., 96 percent of the outcomes were within ±5 mph of the NRMM results). In addition, when less than 95 percent of the data points met the ±5 mph criteria, the 95 percent benchmark is also presented for comparison purposes (e.g.., 81.5 percent of the outcomes were within ±5 mph while 95 percent of the outcomes were within ± 8.6 mph). In some cases, additional data are also provided to give a thorough description of the data dispersion. Validation results are presented in Section 3 and Appendix A of this report.

2. STNDMob OVERVIEW

The STNDMob predicts the maximum safe speed of a ground vehicle given the terrain and environmental conditions. The STNDMob will either calculate or lookup, depending upon the user's requirements, ground mobility speed estimates. The STNDMob currently uses four fidelity levels (i.e., degrees of resolution). As is usually the case, a higher fidelity estimate (i.e., better speed prediction) requires increased input data and additional calculations resulting in potentially longer processing times. Therefore, the STNDMob has multiple levels of fidelity with each higher level of fidelity increasing the resolution of the speed estimate, as well as, the computational demand. Table 1 outlines the available STNDMob resolutions / fidelities. Fidelities 1 and 2 are described in greater detail in Section 2.1.

Fidelities 1 and 2 (Low Resolution) use pre-generated speed lookup tables originating from the NRMM; whereas, Fidelities 3 and 4 (Medium Resolution) use NRMM-based mobility algorithms to calculate predicted speed for real time applications. Fidelity 1 and 2 are referred to as "Level 1- Low Resolution" and Fidelity 3 and 4 are referred to as "Level 2 – Medium Resolution" by the ERDC developers.

2.1 STNDMob Fidelities – Intended Use.

The following describes the intended use for the STNDMob Low and Medium resolution:

- ***Fidelity 1 and 2*** **(Low)** - Intended for wargames or C4ISR systems that move entities over large terrain grids/polygons. These grids/polygons are characterized as homogeneous (e.g., obstacle spacing, vegetation type are consistent across an individual grid/polygon) and are normally 1 km or larger in size (i.e., grid spacing or polygon size). Fidelity 1 and 2 perform some limited routing and will optimize the path within an individual grid/polygon. The route is optimized by either overriding (i.e., going over) or maneuvering around an obstacle. In reality, Fidelity 1 and 2 will normally calculate the speed for maneuvering around an obstacle since the default Fidelity 1 and 2 obstacle can rarely be overridden due to its substantial size (45 in high x 8 ft wide x 8 ft long).

- ***Fidelity 3 and 4*** **(Medium)** - Intended for modeling terrain grids/polygons/features of much smaller size relative to Fidelity 1 and 2. These grids/polygons/features can be roughly the same area as the vehicles being modeled. Obstacles can be overridden within Fidelity 3 and 4 more readily since obstacles can be of varying size.

The STNDMob, at any fidelity, does not perform route planning external to the grid/polygon/feature; therefore, grid/polygon/feature to grid/polygon/feature routing is completed by the scenario author or by a specifically designed routing tool.

Fidelity 1 and 2 (Low) are designed to examine the vehicle/terrain interaction related to areas; whereas, Fidelity 3 and 4 (Medium) are designed to examine the vehicle/terrain interaction at a much smaller (i.e., point) level. Due to the design differences between the STNDMob Low (Fidelity 1 and 2) and Medium (Fidelity 3 and 4) resolutions, a direct comparison of their prediction results was not considered meaningful and therefore was not included in the validation. As mentioned in Section 1, NRMM was used as the basis for comparison for Fidelity 1 and 2.

Table 1. STNDMob Fidelity Descriptions.

Fidelity		Prediction Method
Level 1 - Low	1	• Speed prediction (i.e., maximum safe operating speed given the terrain and conditions) obtained from STNDMob speed tables (i.e., lookup tables) • Speed tables based on pre-generated NRMM results • Twelve "representative" vehicles used to characterize tracked or wheeled ground vehicles • STNDMob selects the representative vehicle whose mobility characteristics best match those of the "specific" vehicle of interest • Defined sets of terrain / environmental conditions • Based on the representative vehicle and terrain/environmental conditions, STNDMob extracts a speed prediction from the appropriate speed table
	2	• Speed prediction obtained by multiplying the Fidelity 1 prediction by a "bin factor" • Unique bin factor (defined in Section 2.2.2) is based on the mobility characteristics of the specific vehicle of interest relative to its representative vehicle
Level 2 - Medium	3	• Speed prediction calculated using mobility algorithms (i.e., no speed tables used) • STNDMob vehicle files used to characterize a platform's mobility characteristics • Twelve "representative" vehicles are used to characterize most tracked or wheeled ground vehicles • STNDMob selects the representative vehicle file whose mobility characteristics best match those of the "specific" vehicle of interest • Situation-specific environmental conditions define the operating situation • Based on the representative vehicle and terrain/environmental conditions, STNDMob calculates a speed prediction
	4	• Speed prediction calculated in the same fashion as the Fidelity 3 prediction except that a specific STNDMob vehicle file, not the representative vehicle file, is used in the speed prediction calculation

2.2 Fidelity 1 and 2 Discussion (Low Resolution).

NOTE: The majority of work discussed in Section 2.2.1 and 2.2.2 can be examined in greater detail within the Standard for Ground Vehicle Mobility, (Ref. 1) and Methodology for the Development of Inference Algorithms for Worldwide Application of Interim Terrain Data to the NATO Reference Mobility Model, (Ref. 2).

2.2.1 Fidelity 1. Fidelities 1 and 2 use hierarchical lookup tables to determine the maximum safe speed estimates. The tables are queried to produce a maximum safe speed for a vehicle under identified terrain and environmental conditions. For example, COMBAT XXI provides the input conditions, described below, to the STNDMob and the STNDMob returns a speed prediction based on the input (i.e., vehicle, environmental, and terrain characteristics).

The vehicle, terrain, and environmental input parameters that are queried by STNDMob Fidelity 1 and 2 to produce a maximum safe speed prediction are as follows:

- Vehicle Bin
- Climate Zone
- Visibility (roads/trails) or Visibility–Obstacle Combination (cross-country only)
- Road Type (roads, trails, or cross-country)
- Surface Condition (dry, wet, snow)
- Soil Trafficability Group Joint Simulation (STGJ)
- Vehicle Pitch (i.e. terrain slope) (%) {-40, -30, -20, -10, 0, 10, 20, 30, 40 (cross-country); -15, -12, -8, -4, 0, 4, 8, 12, 15 (road/trails)}

Vehicle Bin

Twelve representative vehicles are available for query. These twelve vehicles are intended to represent a wide range of military ground vehicles. This was done in order to minimize the number of speed tables that would need to be developed. The procedure requires the user to determine which of the twelve representative vehicles most closely resembles the actual vehicle of interest. The twelve representative vehicles are defined in Table 2.

Table 2. STNDMob Fidelity 1 and 2 Bin Definitions.

Bin No.	Representative Vehicle	Description
1	M1A1	High Mobility Tracked
2	M270 MLRS	Medium Mobility Tracked
3	M60 AVLB	Low Mobility Tracked
4	M1084 MTV	High Mobility Wheeled
5	M985 HEMTT	Medium Mobility Wheeled
6	M917 Dump Truck	Low Mobility Wheeled
7	M1084/M1095	High Mobility Wheeled w/Towed Trailer
8	M985/M989	Medium Mobility Wheeled w/Towed Trailer
9	M911/M747 HET	Low Mobility Wheeled w/Towed Trailer
10	M113A2	Tracked Amphibious Combat Vehicle
11	LAV25	Wheeled Amphibious Combat Vehicle
12	Unmanned All Terrain Vehicle (ATV)	Unmanned Kawasaki Light ATV

The ERDC Binning Methodology is used to associate the vehicle of interest with a representative vehicle. This ERDC methodology is documented within the following technical report: Procedure for Categorizing Ground Vehicles (Ref. 4). Within the report, ERDC discusses successful validation procedures which allow them to have confidence in the methodology. AMSAA also performed a limited validation of the binning methodology as described in Section 3.6. Appendix B compares the bins against one another to examine the sensitivity of the speed predictions going from one bin to another.

Climate Zone

The Worldwide Climatic Zones (Ref. 3) used by STNDMob are listed in Table 3. Terrain databases have been produced for all major climate zones excluding the Tropical Rainy and the Polar Climates. Desert, Humid Subtropical, Humid Continental-Warm Summer, and Undifferentiated Highlands (highlighted in Table 3) are the sub-climate zones selected to represent the four major climate zones. Appendix C discusses world climate zones in greater detail and includes climate zone maps.

Table 3. World Climate Zones.

Climatic Zones (6)	Sub-Climate Zones (13)
A. Tropical Rainy	**1.** Tropical Rainforest **2.** Tropical Savanna
B. Dry	**3.** Steppe **4. Desert**
C. Humid Mesothermal ***(e.g., Sub-Tropical Regions)***	**5.** Mediterranean or Dry Summer Subtropical **6. Humid Subtropical** **7.** Marine West Coast
D. Humid Microthermal ***(e.g., Temperate Regions)***	**8. Humid Continental, Warm Summer** **9.** Humid Continental, Cool Summer **10.** Sub Arctic
E. Polar	**11.** Tundra **12.** Ice Caps
F. Undifferentiated Highlands ***(e.g., Mountainous Regions)***	**13. Undifferentiated Highlands**
Notes: ***Blue Text*** - *Terrain databases have been produced for these climatic zones* ***Red Text*** - *Sub-climate zones selected to represent the four major* blue *climate zones*	

Visibility/Obstacles

Visibility (recognition distance) is defined as the maximum distance an individual can recognize mobility-impeding obstacles within a 360-deg arc. Visibility and obstacle spacing are combined and represented by a single number for cross-country terrain. Roads and trails consider only visibility distance since obstacles are not considered with respect to roads and trails. When visibility and obstacle spacing are combined, the combinations are represented by a VISOBS code. For example, a 25 ft visibility combined with an obstacle spacing of 20 ft produces a VISOBS code of "1". A 25 ft visibility combined with an obstacle spacing of 25 ft produces a VISOBS code of "2". This is done for each of the sixteen possible visibility-obstacle combinations; see Appendix D for a description of the combinations.

- Visibility (feet)
  - 25
  - 50
  - 100
  - 300
- Obstacle Spacing (feet)
  - 20
  - 25
  - 30
  - 150

There is only one type of obstacle simulated in Fidelity 1 and 2, the standard Warfighters' Simulation (WARSIM) obstacle: 45 in high x 8 ft wide x 8 ft long. This is a significant obstacle that can rarely be overridden. Spacing of the obstacles, evenly spaced in a hexagonal pattern, requires the vehicle to either go around or to go over the obstacle, whichever requires less time. If a vehicle is incapable of overriding or maneuvering around the obstacles because the obstacles are placed close together, then STNDMob predicts a speed of zero (i.e., NOGO situation) for that terrain unit. Appendix D discusses visibility and obstacle considerations in greater detail.

Road Type

Once the climate zone and vehicle are specified, the user must input the road type. The specification of road type is used to determine whether obstacle spacing will be considered or not. Roads and trails are assumed to be clear of obstacles and cross-country is assumed to contain non-avoidable obstacles at a uniform spacing. Specific road types are characterized with STGJ codes. The primary terrain types are (please see Appendix E for definitions):

- Roads (includes super-highways, primary, and secondary road types)
- Trails
- Cross-Country

Surface Conditions

Surface conditions examined with STNDMob are as follows:

- Dry-Normal - "Dry" describes the lowest soil moisture and associated soil strength found during the driest consecutive 30-day period of an average rainfall year. "Normal" indicates that the surface is dry and non-slippery
- Wet-Slippery -"Wet" describes soil moisture and associated soil strength found during the wettest consecutive 30-day period for an average rainfall year. "Slippery" indicates that the surface is wet and slippery
- Snow - Snow conditions are dependent upon Climatic Zone chosen; a Snow condition was not developed for Climate Zone 4 (i.e., Desert)]

Please see Appendix E for additional discussion on the topic

NOTE: Normal and Slippery conditions are both represented within the STNDMob speed tables. Only the soft-soil sub-models for fine-grained and coarse grained soils are affected by slipperiness; slipperiness has no affect with regards to snow conditions.

Surface Trafficability Group, JSIMS Mobility Model (STGJ)

STGJ codes are trafficability codes used to characterize the surface strength and vegetation of the terrain that the vehicle is traversing. The STGJ codes originate from the Joint Simulation System (JSIMS) program. STNDMob subsequently converts the STGJ code in question to a Mobility Lookup (MLU) code. MLU codes are used internally to the STNDMob in lieu of STGJ codes to reduce the size of the speed tables. There are approximately 813 STGJ codes to be considered but only 256 MLU codes for cross-country terrain and 23 for on-road, thus one MLU code can represent multiple STGJ codes.

NOTE: STNDMob Fidelity 1 and 2 attempts to include all likely terrain situations that a military platform will traverse. There are soil-vegetation combinations that are conceivable but do not practically exist in the real world; therefore, the MLU codes do not cover every conceivable soil-vegetation combination.

Vehicle Pitch (Slope)

Vehicle pitch is the final input required. STNDMob uses sets of predetermined pitches in order to limit the size of the speed tables. A negative pitch indicates downhill travel while a positive pitch indicates uphill (e.g., -30 = a 30% downhill slope). The available pitches are:

- Cross-Country (%): -40, -30, -20, -10, 0, 10, 20, 30, 40
- Roads/Trails (%): –15, -12, -8, -4, 0, 4, 8, 12, 15

If the slope requested is one of the nine slopes available in the data table, the appropriate speed is chosen for output (or further processing if using Fidelity 2). If the slope is not one of the predetermined slopes, a linear interpolation is performed using the speeds associated with the two slopes bracketing the desired slope. This interpolated speed is then used for output (or further processing if using Fidelity 2). If the slope is outside the stated bounds (i.e., cross-country (less than -40 percent or greater than 40 percent) and road/trails (less than -15 percent or greater than15 percent)), then no speed prediction is made (i.e., speed undetermined).

2.2.2 Fidelity 2. The Fidelity 1 input parameters described in Section 2.2.1 also apply to Fidelity 2; however, an additional input parameter is required to satisfy Fidelity 2. The additional input parameter is *Specific Vehicle Top Speed*. This is the fastest on-road speed (top speed) that the vehicle of interest can achieve. Fidelity 2 attempts to increase resolution by multiplying the Fidelity 1 speed prediction by the ratio of the specific vehicle's top speed to the representative vehicle's top speed. This ratio is referred to as the "bin factor".

$$\text{Bin Factor} = \frac{\text{Specific Vehicle Top Speed}}{\text{Representative Vehicle Top Speed}}$$

$$\text{Fidelity 2 Speed Prediction} = \text{Fidelity 1 Speed Prediction} \times \text{Bin Factor}$$

Table 4 is a visual representation of a speed table used for Fidelity 1 and 2. The speed tables are actually held in a database using the Extensible Markup Language (XML). XML is not easily viewed in a document. Thus Table 4 is only representative of a STNDMob speed table. The speeds in the tables were determined using NRMM runs. ERDC uses a post-processor to convert the NRMM output to XML speed tables. Speeds would be pulled directly for Fidelity 1 predictions. The bin factor would be applied for the Fidelity 2 estimate.

Table 4. Representative Speed Table.

Representative Speed Table										
Title	NRMM Predictions mapped to STGJ Codes									
Climatic Zone	Undifferentiated Highlands									
Bin	High Mobility Tracked (i.e., Bin #1)									
Ground	cross-country									
Condition	dry	Speed (mph) for the given slope/pitch in %								
VISOBS	1	-40	-30	-20	-10	0	10	20	30	40
MLU	1	0.0	0.0	13.2	36.7	26.9	0.0	0.0	0.0	0.0
MLU	2	0.0	0.0	13.2	36.7	26.9	0.0	0.0	0.0	0.0
MLU	3	40.0	40.0	40.0	40.0	12.3	6.0	3.9	1.9	0.0
•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••
MLU	256	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Condition	wet									
VISOBS	1									
MLU	1	0.0	0.0	13.2	36.7	26.9	0.0	0.0	0.0	0.0
MLU	2	0.0	0.0	13.2	36.7	26.9	0.0	0.0	0.0	0.0
MLU	3	38.1	40.0	40.0	40.0	11.6	5.0	0.0	0.0	0.0
•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••
MLU	256	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ground	Road									
Condition	Dry	Speed (mph) for the given slope/pitch in %								
VIS	1	-15	-12	-8	-4	0	4	8	12	15
MLU	726	27.7	30.0	30.0	30.0	26.6	14.6	0.0	0.0	0.0
MLU	727	27.7	30.0	30.0	30.0	26.6	14.6	0.0	0.0	0.0
MLU	728	30.0	30.0	30.0	23.6	12.3	8.7	6.8	5.5	4.8
•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••
MLU	749	30.0	30.0	30.0	30.0	23.5	12.3	8.8	6.8	5.8

NOTE: Speeds shown are for example purposes only.

3. VALIDATION - FIDELITY 1 AND 2

To perform the validation, one must attempt to answer the question "To what degree do STNDMob speed predictions reflect real-world outcomes?" In other words, does the STNDMob produce realistic speed estimates for ground vehicle mobility over varying terrain and environmental conditions? The primary difficulty is obtaining real world outcomes to use for comparison. As indicated in the Army Standards Repository System, NRMM is the Army's standard (Ref. 5) for ground mobility predictions and, as such, was used as the basis for "ground truth."

The speed tables in STNDMob are developed using the NRMM. The NRMM is the standard by which the STNDMob Fidelity 1 and 2 predictions are evaluated. This creates a situation where the items being validated (i.e., STNDMob speed predictions) are being compared against a baseline (i.e., NRMM speed predictions) originating from the same source (i.e., NRMM). In this case, this is beneficial as it allows one to verify that the code has been implemented properly by assuring that the STNDMob is returning the proper speed predictions. Given that the correct predictions are being pulled from the speed table, the output would be considered valid since the predictions are based directly on NRMM results.

The vehicle files, obtained from ERDC, were examined to assure that no obvious anomalies were present and that they sufficiently characterized the twelve representative vehicles. The ERDC vehicle files were used throughout this validation effort in order to achieve consistency between the NRMM comparison runs and the STNDMob speed tables.

The next section addresses the various validation topics and is organized in the following manner:

1. Question - Describes the validation question being considered
2. Methodology - Discusses how the validation question was addressed
3. Result - Identifies findings

It should be noted that some areas were not sufficiently examined, since the subject matter was outside of AMSAA's expertise. These study limitations are described below:

Study Limitations

- As discussed earlier in this document, the STGJ and MLU trafficability codes were cross referenced to allow for a reduction in speed table size. ERDC researchers performed the crosswalk. AMSAA does not have the vegetation and soil expertise to adequately perform a validation of this crosswalk.

- Once the crosswalk between STGJ and MLU trafficability codes had been established, it was necessary for ERDC to assign MLU attribute values into NRMM terrain files. By using an inference methodology, they were able to convert MLU trafficability codes into specific soil - vegetation combinations within the NRMM terrain files. These NRMM terrain files were then used to produce the speed predictions for the STNDMob speed tables. It is critical that these MLU codes are accurately represented within the NRMM environment since they are the basis for the predictions within the speed tables. If this inference methodology is incorrect, then the terrain files are incorrect resulting in inaccurate speed predictions. AMSAA does not have the vegetation and soil expertise to adequately perform a validation of this procedure.

3.1 Question #1 – Are the twelve representative vehicles accurately characterized within the NRMM vehicle files?

Methodology – The ERDC NRMM vehicle files were examined for completeness and accuracy. To perform this task, the ERDC files were compared to the AMSAA vehicle library files to determine if the ERDC and AMSAA vehicle files were similar in content. Most of these vehicle files have been used in studies by AMSAA and ERDC for several years, thus the vehicle files have been examined on several occasions. If the ERDC and AMSAA files were similar, then the ERDC vehicle files were considered reasonable representations of the platforms in question. If they were not, an effort was made to determine the reason for the inconsistency and then to determine a corrective solution.

This was **not** an effort to certify that the vehicle files were fully correct, but to simply assure that the ERDC vehicle files were sufficiently correct for the validation effort. NRMM uses the vehicle files to create the speed tables, thus errors in the vehicle files will have an impact upon the STNDMob's capability to accurately predict speeds.

Result – Most of the twelve representative vehicle files were found to be satisfactory for validation purposes; however, in a few cases there were problem areas (e.g., M1A1 plow data, Armored Vehicle Launched Bridge (AVLB) dimensions). In these cases, AMSAA identified the issues to ERDC, who subsequently updated the vehicle files and constructed new speed tables. This validation was based on the updated vehicle files and speed tables.

One should keep in mind, that questions remain regarding NRMM's capability to address vehicles in the unmanned ATV category (Bin #12). The Army's experience is limited with respect to NRMM and light weight vehicles. ERDC based the light unmanned vehicle file on tests that they conducted, thus this vehicle file is likely a very good unmanned ATV representation. The concern centers on the use of NRMM to make satisfactory speed predictions. The ATV under test weighs approximately 800 lbs with a rider. Only limited work has been conducted to determine NRMM's lower weight limit for valid predictions. ERDC believes the lower limit for NRMM to be on the order of 500 lbs. The work to thoroughly validate the lower NRMM weight limit still remains. This study uses ERDC's unmanned Kawasaki light ATV vehicle file for validation purposes.

3.2 Question #2 – Given specific vehicle and terrain characteristics, does the STNDMob produce expected and accurate speed predictions?

Methodology – This question is the crux of the Fidelity 1 and 2 validations and verifies that the STNDMob is selecting the correct predictions from the speed tables. To answer the question, a series of queries were submitted to the STNDMob regarding specific vehicle and environmental conditions. The vehicles in question are the twelve representative vehicles described in Table 2. The STNDMob outcome was compared to the resulting NRMM prediction using the same vehicle and environmental parameters. The STNDMob query was made at a vehicle pitch value that did **not** require the STNDMob to perform an interpolation calculation. Questions regarding pitch interpolation are addressed in Section 3.3.

These steps were used to verify that the STNDMob selected the proper value from the speed tables and that the speed tables were correctly populated. If the STNDMob and NRMM results were comparable, then the STNDMob predictions were considered valid.

Result - The initial plan called for an appropriate number of STNDMob queries to be used to sufficiently verify that the appropriate speed predictions were being pulled from the speed tables. In the end, it was determined that a check of the entire population consisting of over three million speed predictions was feasible. Examining the entire population was quite advantageous as many discrepancies were discovered and reported to ERDC. ERDC then corrected the problems and issued updated speed tables. This method was so successful that the STNDMob and NRMM speed prediction discrepancies are now no greater than .06 mph for the entire population. Details of these findings are found in the following paragraphs.

The STNDMob speed tables are populated with 3,668,544 predictions. The number of speed table predictions may be determined by multiplying across the rows in Table 5 and then adding the products. Note that for cross-country terrain there are 187 MLUs as opposed to 255 MLUs mentioned previously. This is because some MLUs are considered redundant and therefore not used. These MLUs have been excluded from the total speed table population, since no predictions are based on them. Also, no Snow scenarios have been created for the Desert climate, thus there are only three climate zones for the Snow scenario rather than four.

Table 5. STNDMob Speed Table Population.

Terrain	Scenario	Climate Zone	MLU	VISOBS	Slope	Vehicle	TOTAL
Cross-Country	DRY	4	187	16	9	12	1,292,544
Cross-Country	WET	4	187	16	9	12	1,292,544
Cross-Country	SNOW	3	187	16	9	12	969,408
Road/Trail	DRY	4	24	4	9	12	41,472
Road/Trail	WET	4	24	4	9	12	41,472
Road	SNOW	3	3	4	9	12	3,888
Trail	SNOW	3	21	4	9	12	27,216
							3,668,544

Each speed table value was checked against its corresponding NRMM value. To get the corresponding output from NRMM, the twelve representative vehicles were run in NRMM using corresponding STNDMob environmental conditions. Only environmental conditions that explicitly existed in STNDMob were used; therefore, no interpolation for vehicle pitch was required. NRMM produced a file that identified the speed prediction for each environmental condition. The speed predictions in this file were then directly compared to the STNDMob speed predictions. As noted earlier, the STNDMob and NRMM predictions were within ±0.06 mph for the entire 3.6+ million population.

In a related matter, configuration control of the speed tables and associated files should be examined. At this point, Fidelity 1 and 2 speed tables and the vehicleTypeIDMap.xml file do not include version control numbers. The speed tables and the vehicleTypeIDMap.xml file are stored at the Joint Data Center, AMSAA, where they are distributed to the User community. Undoubtedly, these data will be modified from time to time, and to assure the most up-to-date data are being delivered to users, the files should be uniquely identified and managed through the use of a version control number(s).

There is a similar situation with the STNDMob Fidelity 3 and 4 vehicle files. The files do have a unique creation date included. While this identification is very useful, a version number might be more easily tracked and maintained.

3.3 Question #3 – How accurate is STNDMob interpolation methodology in predicting speed on slope?

Methodology – If the STNDMob query requests one of the specific STNDMob speed table slopes (i.e., {Cross-Country (%): -40, -30, -20, -10, 0, 10, 20, 30, 40}; {Roads and Trails (%): –15, -12, -8, -4, 0, 4, 8, 12, 15}) then the speed prediction is pulled directly from the speed tables. If the requested slope is not one of the predefined slopes, then STNDMob performs a linear interpolation in order to produce a speed prediction.

For example, if a cross-country terrain slope of 25 percent were requested from STNDMob, then the STNDMob would select the 20 percent and 30 percent slope speeds and interpolate to produce a speed for the 25 percent slope.

To quantify how this interpolation affects the solution, one must compare the STNDMob interpolated speeds to the NRMM calculated speeds on identical slopes. Producing NRMM speed predictions for the desired slopes required altering the NRMM terrain files that were originally used to develop the STNDMob speed tables by including the new slopes into the terrain files. Initially AMSAA was concerned that when modifying the slopes in the NRMM terrain file, the soil characteristics (e.g., remolding cone index) should also be modified because soil characteristics sometimes change as a function of slope. This modification would have then required more knowledge about the soil conditions than was available to AMSAA. Based on our discussions with ERDC and an examination of the terrain files, the soil strength issue is considered a minor study limitation given the small number of terrain units that are impacted. AMSAA examined each terrain unit used to build the speed tables in order to determine how many potential cases would exist. There are 14,552 cases, out of 451,008 terrain units, where the soil characteristics would have varied with slope. This represents only 3.2 percent of the terrain units that can potentially skew the overall interpolation results and was considered negligible.

It was determined, as with Question #2, that it was feasible to examine the entire population of speed table values. To quantify the differences between NRMM and STNDMob interpolation results, the current speed table slopes were modified by a fixed amount. The slope values were incremented by +5 percent for cross-country terrain (cross-country slopes are indexed by 10 percent) and +2 percent for road and trail terrain (most road and trail slopes are indexed by 4 percent). This tested the midpoint of the respective slope ranges. In addition, because the off-road slope range was large (10 percent increments), an additional check was performed at +2 and +8 percent on the off-road terrains to ensure that a representative cross sample was taken. STNDMob Fidelity 1 was used throughout this testing with the twelve representative vehicles.

EXAMPLE: For the +8 percent slope variation, the tested slopes were -32 (i.e., -40% + 8%), -22 (i.e., -30% + 8%), -12, -2, 8, 18, 28, 38, and 48%. NRMM made speed predictions based on terrain units with these specific slopes and, then, STNDMob made speed predictions for these slopes based on interpolation between the pre-defined slopes. The results were then compared (STNDMob speed prediction – NRMM speed prediction). A negative answer was an indication that the NRMM produced a faster speed prediction.

Moreover, the mathematical operation of the STNDMob interpolation was examined by manually interpolating values within the STNDMob speed tables and comparing these interpolations directly to those produced by the STNDMob. This procedure was completed on 36 samples.

Results – The mathematical operation of the STNDMob interpolation appears to be functioning correctly. Of the 36 samples manually tested, all 36 matched the manually calculated results.

The interpolated STNDMob results vary from the NRMM results only slightly when viewed as a whole. As can be seen in Figure 1, the majority of the interpolated data for off-road terrain with a +5 percent change in the slope matched the results from the NRMM. The figure shows that of the 3,159,552 cross-country data points found through interpolation, almost 2.9 million (approximately 94 percent) were within 1 mph of the NRMM predicted speed. The mean error for this off-road terrain population was -0.01 mph with a standard deviation of 0.76. The error range was -14 to 11 mph. The reasons for the larger speed discrepancies are explained at the end of this section.

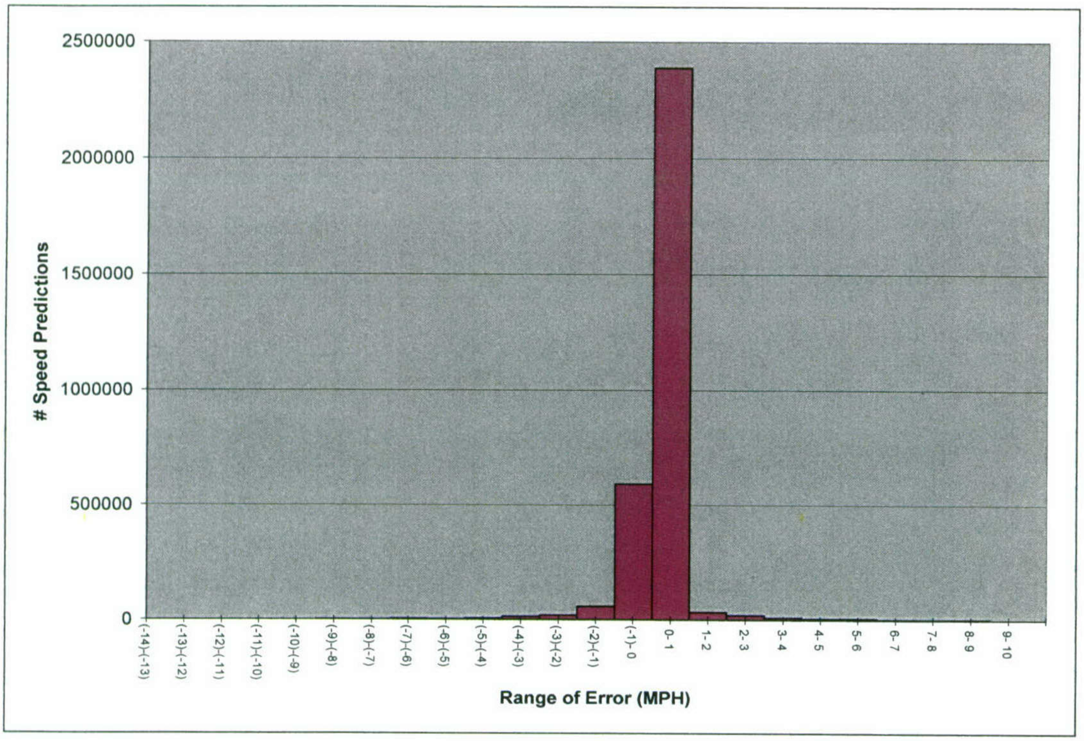


Figure 1. +5 Percent Slope Variation Results (Representative Vehicles, Cross-Country, Dry/Wet/Snow). NOTE: Lower range value is inclusive / Upper range value is exclusive for Range of Error (mph).

The additional assessment that was performed using a +2 and +8 percent increase produced comparable results. In this case there were 6,319,104 cross-country data points in the population. Almost 6.1 million (approximately 96 percent) were within 1 mph of the NRMM predicted speed The average error was -0.006 mph with a standard deviation of 0.574. The range of errors was from -17 to 14 mph.

The road/trail terrain showed similar results using a +2 percent slope increase variation, see Figure 2. The figure shows that of the 101,376 road data points found through interpolation, the average difference between the NRMM and STNDMob was -.038 mph with a standard deviation of 0.862. There were 91,143 (90 percent) of the data points within 1 mph of the NRMM results. The range of errors was from -13 to 8 mph.

Although the average errors and standard deviations were small, the few data points that contained large errors (e.g., 17 mph, etc.) were investigated further. The investigation revealed that these large discrepancies were the result of interpolations over slope ranges that produced significant speed changes in NRMM.

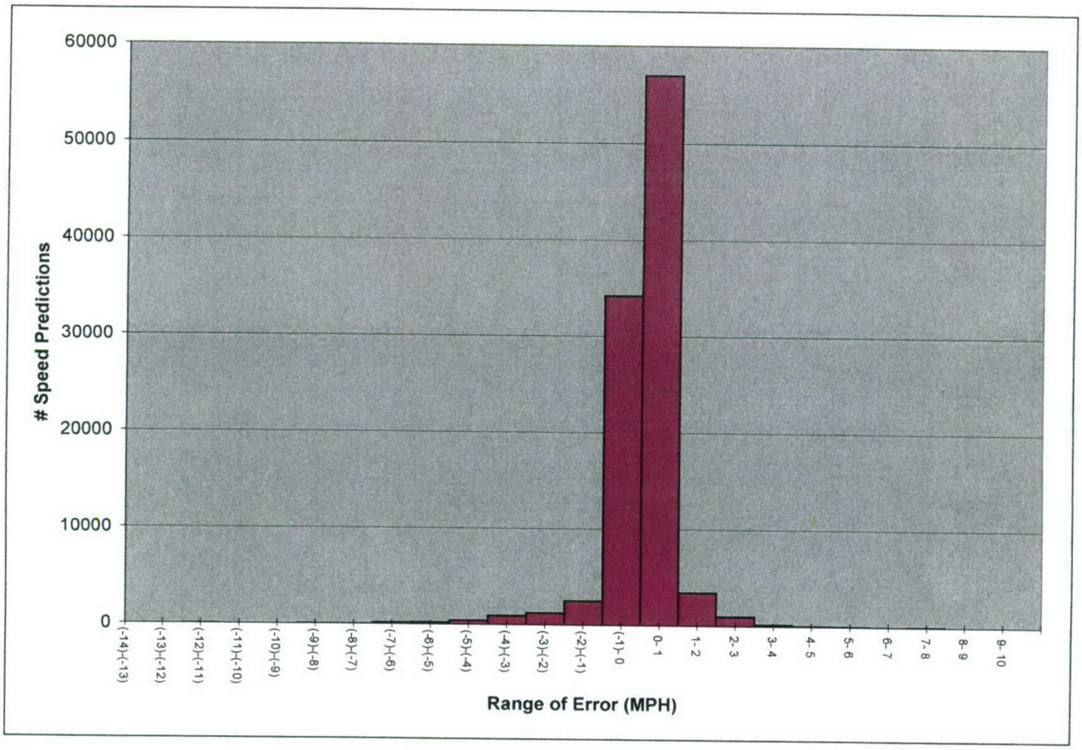


Figure 2. +2 Percent Slope Variation Results (Representative Vehicles, Road/Trail, Dry/Wet/Snow). NOTE: Lower range value is inclusive/Upper range value is exclusive for Range of Error (mph).

For example, NRMM indicated that the Kawasaki (Bin 12) had a speed of 27 mph on a 10 percent slope while it had a speed of zero on a 20 percent slope. For a 15 percent slope, STNDMob predicted a speed of almost 14 mph using the interpolation methodology. The NRMM predicted speed was almost 25 mph for a 15 percent slope, a discrepancy of 11 mph. A review of the Kawasaki data shows that over the 10 percent to 20 percent slope range, the change in speed is not linear. The speed does not change significantly until after 17 percent slope. This difference between the assumed linear change of speed with slope and the NRMM predicted non-linear relationship causes the large error. Several other investigations led to similar results. The data previously presented show that for the vast majority of cases the linear assumption is valid.

3.4 Question #4 – For Fidelity 1 and 2, how do NRMM and STNDMob speed predictions compare for non-representative vehicles?

Methodology – Definition: A non-representative vehicle is a vehicle that is not the designated bin vehicle as shown in Table 2. For example, an M2A2 is not one of the vehicles listed in Table 2 as representing a bin so it is considered a non-representative vehicle.

Fidelity 1 and 2 are considered low resolution predictions. As described in Section 2.2.2, Fidelity 2 uses a bin factor that serves as a multiplier to refine the speed estimate relative to Fidelity 1. In order to quantify the differences between NRMM and STNDMob Fidelity 1 and 2, speed predictions between all three were compared. Three sets of modeling results were examined to make the comparisons.

- NRMM w/ non-representative vehicles
- STNDMOB Fidelity 1 w/ non-representative vehicles
- STNDMOB Fidelity 2 w/ non-representative vehicles

A total of eleven non-representative vehicles, one for each bin, were modeled by NRMM and the STNDMob Fidelity 1 and 2, see Appendix A for results. In the case of the unmanned ATV (bin 12), AMSAA has no similar alternative vehicle file. The same environmental parameters were used in each case to allow for a fair comparison.

Result – Initial checks were conducted to verify that the basic STNDMob Fidelity 1 and 2 functionality was working properly. Section 3.2 describes the Fidelity 1 check, and shows it to be performing properly. For Fidelity 2, the set of the twelve representative vehicles was used to examine its basic functionality. The bin factor used in Fidelity 2 equals 1.0 for representative vehicles; therefore, the Fidelity 2 speed predictions should be very close to the NRMM and STNDMob Fidelity 1 speed predictions.

All twelve representative vehicles were used as the basis for predicting speed on terrain. The entire 3.6+ million entity speed table population (i.e., roads, trails, and cross-country) was examined without slope interpolation. The NRMM to STNDMob Fidelity 2 comparisons yielded no errors outside ±0.06 mph; thus, the basic STNDMob Fidelity 2 functionality was operating as designed for representative vehicles.

The next experiments compared speed predictions for the eleven non-representative vehicles across the three tools (i.e., NRMM, STNDMob Fidelity 1, and STNDMob Fidelity 2). Due to the size of the speed table populations, samples were taken to quantify the differences between the NRMM, STNDMob Fidelity 1 and Fidelity 2 predictions. As stated earlier, all eleven bins were examined and are discussed in Appendix A. For an individual vehicle, there are 100,000+ elements in each speed table. In order to reduce the population so that a spreadsheet could handle the data volume, only one climate zone of the four was examined per vehicle. A total of six subtests were performed. The Bin 1 examination is described in the following section. Discussion related to the other ten bins can be found in Appendix A.

The Bin 1 non-representative vehicle used for this test is the U.S. Army's M2A2, Figure 3. The bin factor for the M2A2 is 0.92. The representative vehicle for Bin 1 is the U.S. Army's M1A1, Figure 4. All STNDMob speed table predictions for Bin 1 therefore originated from NRMM predictions of the M1A1. In order to use these M1A1 predictions to represent the M2A2's speed, the M2A2's bin factor (0.92) is applied to the M1A1 predictions when using Fidelity 2. The bin factor is not applied when using Fidelity 1. As described in Section 2.2.2, the bin factor is simply the ratio of the non-representative vehicles top speed to the representative vehicles top speed. All tests were performed using Climate Zone 13, Undifferentiated Highlands, with no interpolation. The tests were as follows:

Figure 3. M2A2.

Figure 4. M1A1.

- Cross-Country – Dry
- Cross-Country – Wet
- Cross-Country / Trail – Snow
- Road / Trail – Dry
- Road / Trail - Wet
- Road – Snow

The terrain files dictate whether trails were associated with roads or cross-country. The findings for each case are as follows:

Cross-Country – Dry. A key element examined was the difference between the M2A2 STNDMob Fidelity 1 and 2 predictions and the NRMM predictions. This difference is simply referred to as the "prediction delta". With Fidelity 2 implemented, the tendency was for the mean, standard deviation, and range to decrease relative to the Fidelity 1 statistics as shown in Table 6. Within Table 6, Range refers to the absolute difference between the worst case over- and under-predictions. The Minimum is the worst case under-prediction, and the Maximum is the worst case over-prediction with worst case being defined as where the prediction delta is greatest. Over- and under-predictions are defined later in this section. "Count" identifies the number of terrain units that were used to base the speed predictions.

Table 6. M2A2 Prediction Delta Fidelity Comparison {Climate Zone 13, Cross-Country, Dry}.

Fidelity 1 (STNDMob – NRMM Prediction)		Fidelity 2 (STNDMob – NRMM Prediction)	
	Dry		Dry
Mean	0.56	Mean	0.19
Standard Deviation	3.02	Standard Deviation	2.60
Range	35.61	Range	32.29
Minimum	-16.80	Minimum	-16.80
Maximum	18.81	Maximum	15.49
Count	26928	Count	26928

All units are mph except for "Count"

Fidelity 2 predictions are not always more accurate relative to Fidelity 1 predictions. The STNDMob bin factor is applied to both over- and under- predictions equally. When the bin factor is less than1.0 and the STNDMob over-predicts relative to NRMM predictions, the application of the bin factor moves the estimate closer to the NRMM baseline prediction. If the STNDMob under-predicts and the bin factor is less than 1.0, then the application of the bin factor moves the estimate further from the NRMM baseline prediction. If the bin factor is greater than 1.0, then the opposite is true.

This phenomenon is readily seen in Figure 5. In the upper right portion of the chart, the STNDMob is over-predicting (i.e., STNDMob is predicting a faster speed than NRMM; thus the STNDMob prediction minus the NRMM prediction yields a positive value). When the 0.92 bin factor is applied in this situation, the resulting Fidelity 2 curve is moved closer to the NRMM baseline (i.e., where STNDMob – NRMM = 0 mph). In the lower left portion of the chart, the STNDMob is under-predicting so when the bin factor is applied, the resulting Fidelity 2 curve is moved further away from the NRMM baseline; this makes the Fidelity 2 prediction slightly less accurate than the Fidelity 1 prediction. Figure 5 can be used to identify whether the prediction delta is over, under, or even. The reader should note that each prediction delta point may mask multiple points stacked one upon another. The prediction delta types are defined as follows:

Over: STNDMob Prediction – NRMM Prediction = Positive Value
Even: STNDMob Prediction – NRMM Prediction = 0 [i.e., STNDMob and NRMM prediction are the same]
Under: STNDMob Prediction – NRMM Prediction = Negative Value

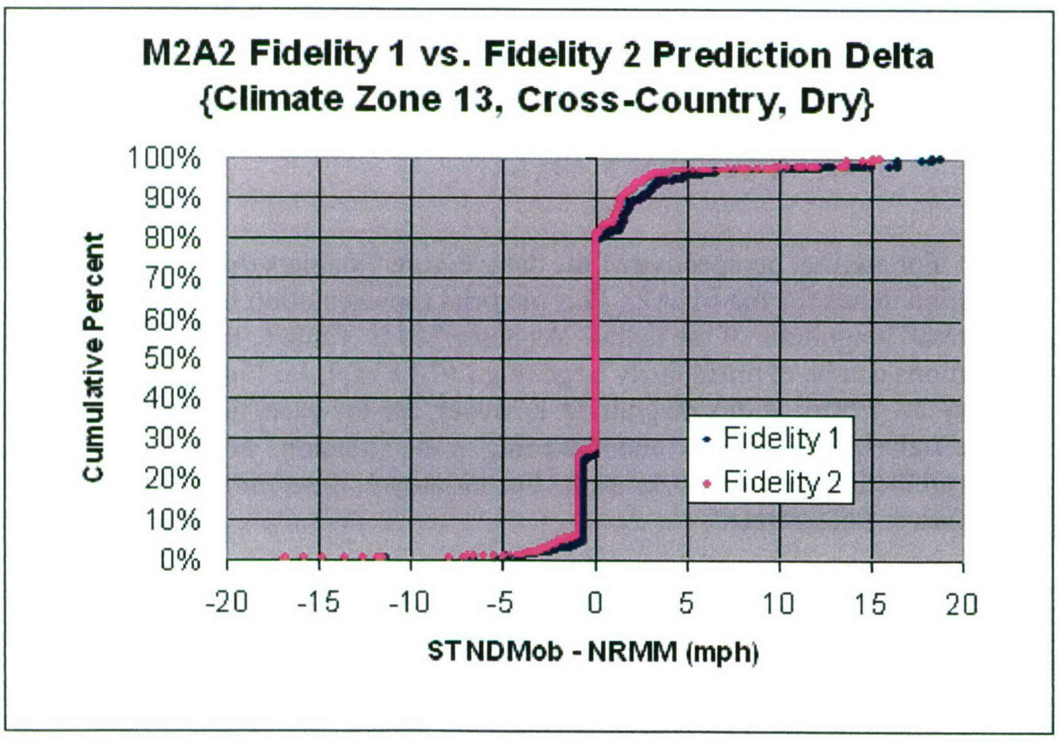
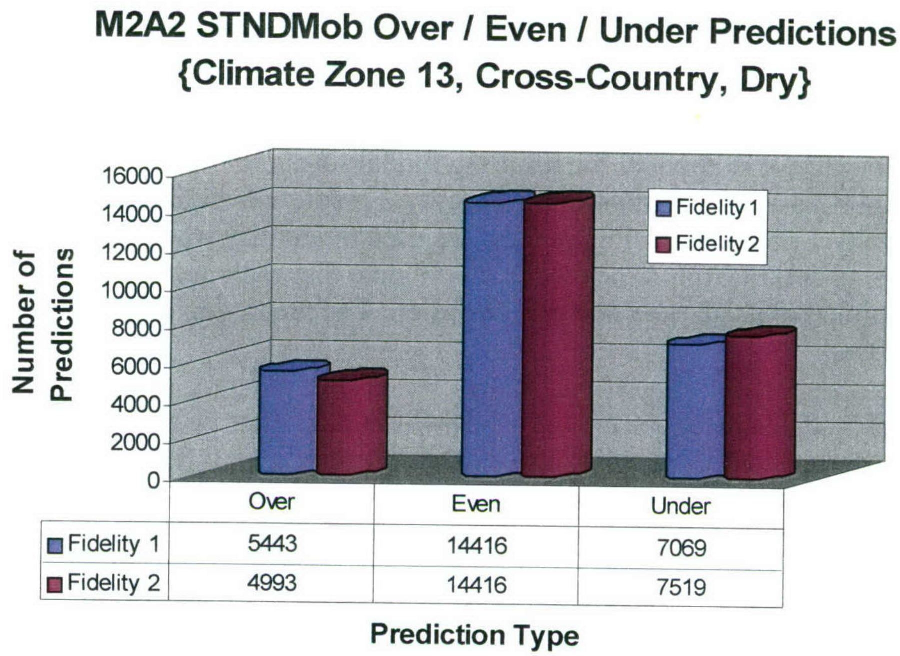


Figure 5. M2A2 Fidelity 1 vs. Fidelity 2 Prediction Delta {Climate Zone 13, Cross-Country, Dry}.

Figure 6 alleviates the stacking issue and identifies the exact number of over, under, and even-predictions. In the case of the M2A2, there are more under-predictions than over-predictions. Due to the bin factor, Fidelity 2 has 3.3 percent more under-predictions than Fidelity 1. Fidelity 2 produced more under-predictions, but it also produced fewer over-predictions. Over-prediction speed deltas are generally larger relative to under-prediction speed deltas, thus the overall effect of applying the Fidelity 2 bin factor (.92) delivers better prediction accuracy relative to Fidelity 1. The overall effect can be seen in the mean and standard deviation changes identified in Table 6.



	Over	Even	Under
Fidelity 1	5443	14416	7069
Fidelity 2	4993	14416	7519

Figure 6. M2A2 STNDMob Over / Even / Under-Predictions {Climate Zone 13, Cross-Country, Dry}.

For another perspective of the data, Figure 7 depicts the absolute value of the prediction deltas for the M2A2. This pictorial representation is useful in quickly gauging the overall magnitude of the deltas. As described in Table 6, the range of STNDMob predictions can be at times fairly large (e.g., +18.8 mph for Fidelity 1 and +15.5 mph for Fidelity 2). Errors of this magnitude, however, are the exception rather than the rule. Figure 7 also gives a clearer understanding of the situation. For Fidelity 1, 95.0 percent of the predictions are within ±5 mph. For Fidelity 2, the number of predictions within ±5 mph rises to 96.2 percent.

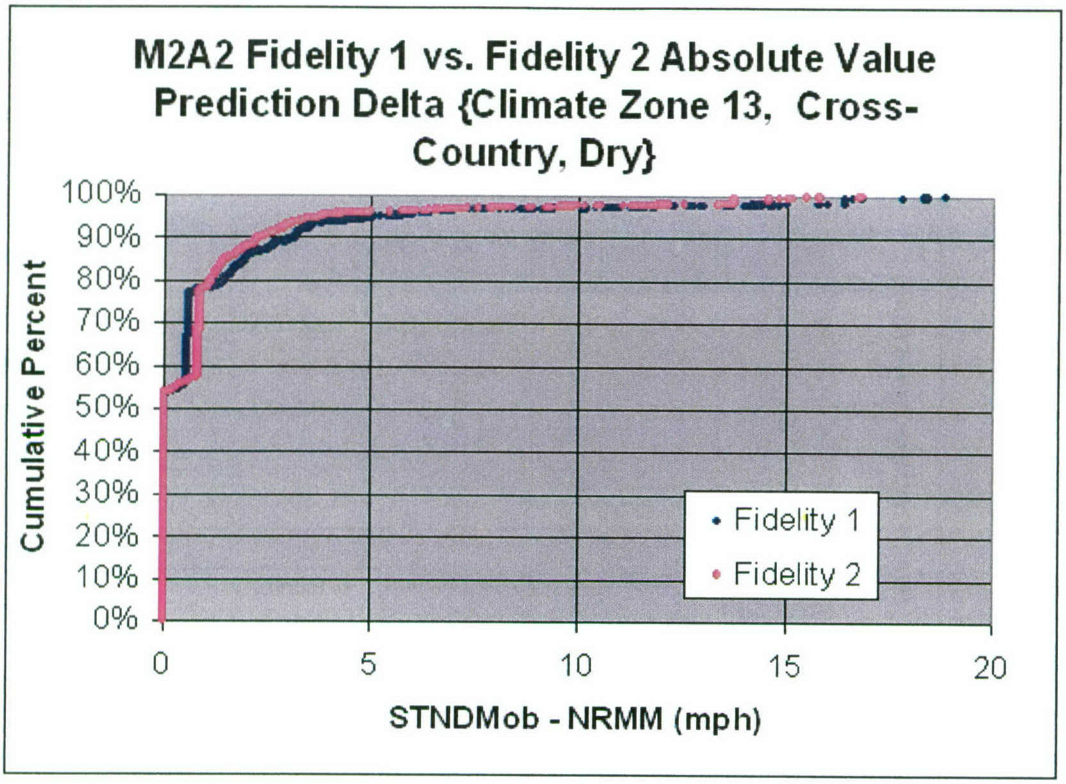


Figure 7. M2A2 Fidelity 1 vs. Fidelity 2 Absolute Value Prediction Delta {Climate Zone 13, Cross-Country, Dry}.

Figure 8 is a scatter plot depicting the M2A2's STNDMob speed predictions versus NRMM speed predictions. As expected, the Fidelity 2 cases are located directly below their associated Fidelity 1 case due to the application of the bin factor. If the bin factor were greater than 1.0, then the Fidelity 2 cases would be directly above their Fidelity 1 counterparts. Figure 8 provides an excellent graphic regarding how well the STNDMob is predicting. If the STNDMob predicted perfectly (i.e., exactly the same as the NRMM), then all of the data points would fall on the yellow reference line. One interesting item of note is the vertical data spikes that can be seen at 16.8 and 22.6 mph. At these points, the maximum prediction deltas are occurring between the STNDMob and NRMM predictions (discussed further later in this section).

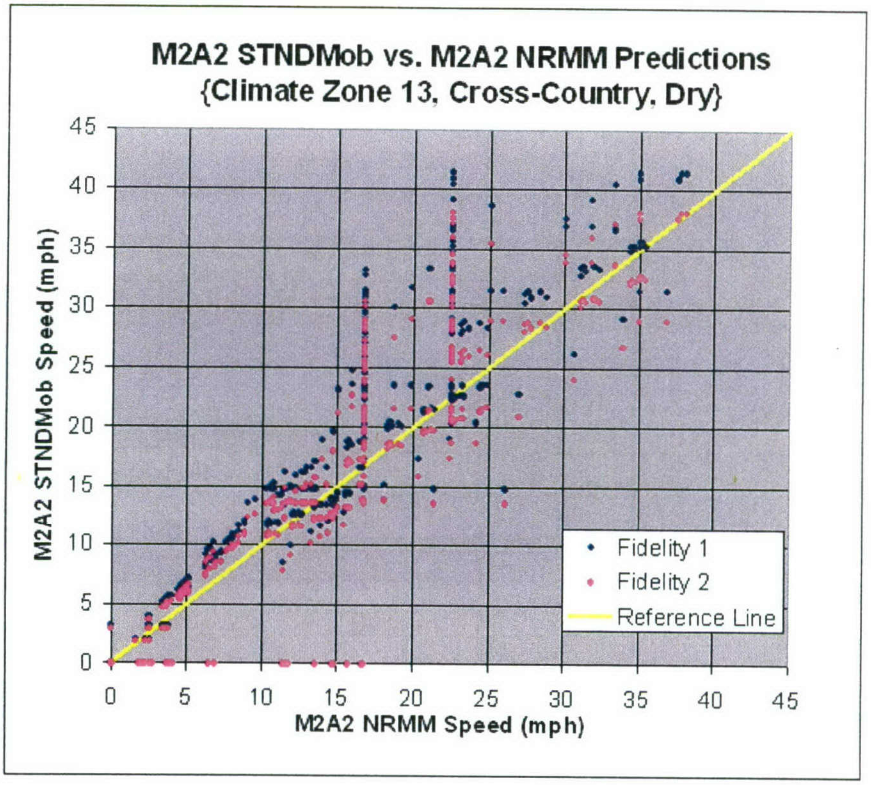


Figure 8. M2A2 STNDMob vs. M2A2 NRMM Predictions {Climate Zone 13, Cross-Country, Dry}.

Within an NRMM vehicle file, there are speed limiting factors that are used to bound a vehicle's speed given certain environmental conditions. One of these limiting factors is the maximum driver absorbed energy given the vehicle's speed and the root mean square of the surface roughness. The maximum absorbed power for a driver over an eight hour period is traditionally given at six watts. To keep below the six watt maximum value, in rougher terrain, the speed is set at a lower acceptable limit. The M2A2 and M1A1's roughness versus speed relationships for six watts maximum absorbed power is shown in Table 7 and Table 8.

Table 7. M2A2 Vehicle Ride Characteristics (6 watts max).

Surface Roughness (rms)	0	1.0	1.5	2.0	2.5	3.0	3.5
Speed Limit (mph)	100	35	19.5	15	12	10	2

Table 8. M1A1 Vehicle Ride Characteristics (6 watt max).

Surface Roughness (rms)	0	1.57	1.68	1.86	2.1	2.52	2.83
Speed Limit (mph)	100	50.2	37.9	30.8	24.7	18.1	14.8

When Table 7 and Table 8 are compared, it is clear that the M1A1 can be driven over a specified surface roughness at a greater speed before being limited by driver absorbed power. When M2A2 speeds are predicted using NRMM, the ride limiting speeds are taken from Table 7. When M2A2 speeds are predicted using STNDMob, the ride limiting speed is taken from Table 8, and the Table 8 ride limiting speeds are considerably higher relative to Table 7. Table 8 is used because the representative vehicle for the M2A2 is the Bin 1 representative vehicle (i.e., M1A1). The M2A2's NRMM predictions are capping the speed, thus the vertical data groupings.

The two predominant data spikes, shown in Figure 8, occur at 16.8 mph and 22.6 mph. Upon examination of the surface conditions during these periods, the roughness conditions are 1.8 rms and 1.4 rms, respectively. Interpolating within Table 7 for the given surface roughness values, the 16.8 and 22.6 mph speed limits can be obtained. With respect to the 1.8 and 1.4 rms speed limitations, there were 718 occurrences (out of a sample population of 26,928) that resulted in a STNDMob – NRMM delta prediction of 5 mph or greater (2.7 percent).

For Fidelity 1 and 2, speed limiting factors such as ride will likely be the source of the greatest differences between STNDMob and NRMM predictions. In the case of the M2A2, vehicle ride characteristics were the culprit, but other limiters can also have an impact (e.g., braking capability, tire maximum speed). This is a limitation for Fidelity 1 and 2. Given that one vehicle is being represented with a similar, but not exact, vehicle, this type of error is to be expected.

Also, upon examination of Figure 8, there are instances for which NRMM predicted that the M2A2 could move while the STNDMob indicated a NOGO situation (i.e., Speed = 0 mph), thus producing some notable differences between the STNDMob and NRMM predictions. This situation is graphically depicted by the data points located along the x-axis. Only Fidelity 2 data points are shown along the x-axis because the Fidelity 1 points are masked by the Fidelity 2 points. This depicts a situation where NRMM indicates that the M2A2 can traverse the terrain while the M1A1 (i.e., the representative vehicle being used by STNDMob) cannot. Upon examination of the M1A1's NRMM prediction for the terrain in question, it was confirmed that the M1A1 cannot traverse the terrain (e.g., due to soil, slope, and vegetation resistance). The M2A2 did not have this restriction and could, therefore, traverse this terrain. RMS and NOGO limitations combined produced prediction deltas outside ± 5 mph in 3.3 percent of the sample population.

The terrain (Climate Zone 13, Dry) produced over 50 percent NOGO situations (speed-made-good = 0 mph). The high number of NOGO occurrences was attributed to large test vehicles attempting to traverse terrain having closely spaced, impassable, obstacles. In the end, over 95 percent of the Fidelity 1 and 96 percent of the Fidelity 2 estimates were within ±5 mph of the M2A2's NRMM baseline.

Cross-Country – Wet. In order to further compare STNDMob Fidelity 1 and 2 predictions to the NRMM baseline, the procedures previously described in Cross-Country – Dry conditions were repeated for Cross-Country – Wet conditions. As before, the U.S. Army's M2A2 was used as the test platform.

Table 9 identifies the statistics for the two conditions (i.e., Dry and Wet). There were minor changes in the statistics, but, generally, the prediction deltas from Dry to Wet

Table 9. M2A2 {Climate Zone 13, Cross-Country, Dry/Wet}.

Fidelity 1 (STNDMob – NRMM Prediction)			Fidelity 2 (STNDMob – NRMM Prediction)		
	Dry	Wet		Dry	Wet
Mean	0.56	0.24	Mean	0.19	-0.09
Standard Deviation	3.02	2.70	Standard Deviation	2.60	2.43
Range	35.61	35.90	Range	32.29	32.56
Minimum	-16.80	-16.80	Minimum	-16.80	-16.80
Maximum	18.81	19.10	Maximum	15.49	15.76
Count	26928	26928	Count	26928	26928

All units are mph except for "Count"

conditions were very similar.

Comparing the graphs of the Dry and Wet environments, Figure 9, Figure 10, and Figure 11 are very similar to the earlier Dry condition graphs. This indicates that the NRMM and STNDMob prediction delta is consistent between Dry and Wet environmental conditions. In the case of Wet conditions, 96 percent of Fidelity 1 and Fidelity 2 predictions were within ±5 mph of the NRMM baseline. This is consistent with the STNDMob predictions in a Dry environment.

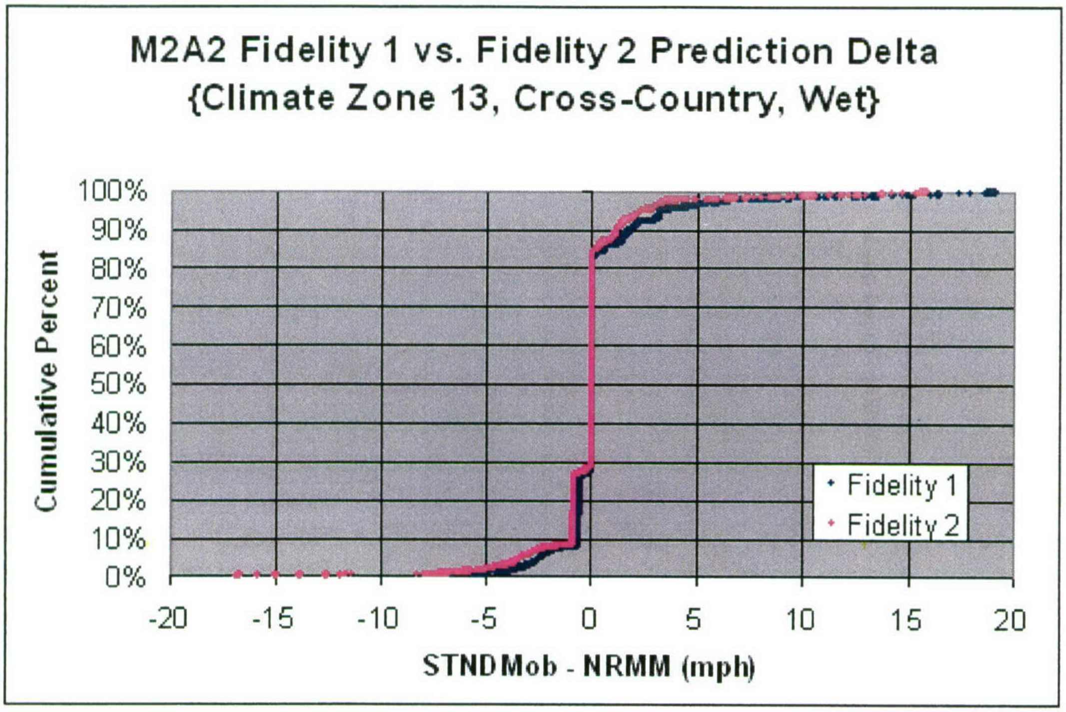


Figure 9. M2A2 Fidelity 1 vs. Fidelity 2 Prediction Delta {Climate Zone 13, Cross-Country, Wet}.

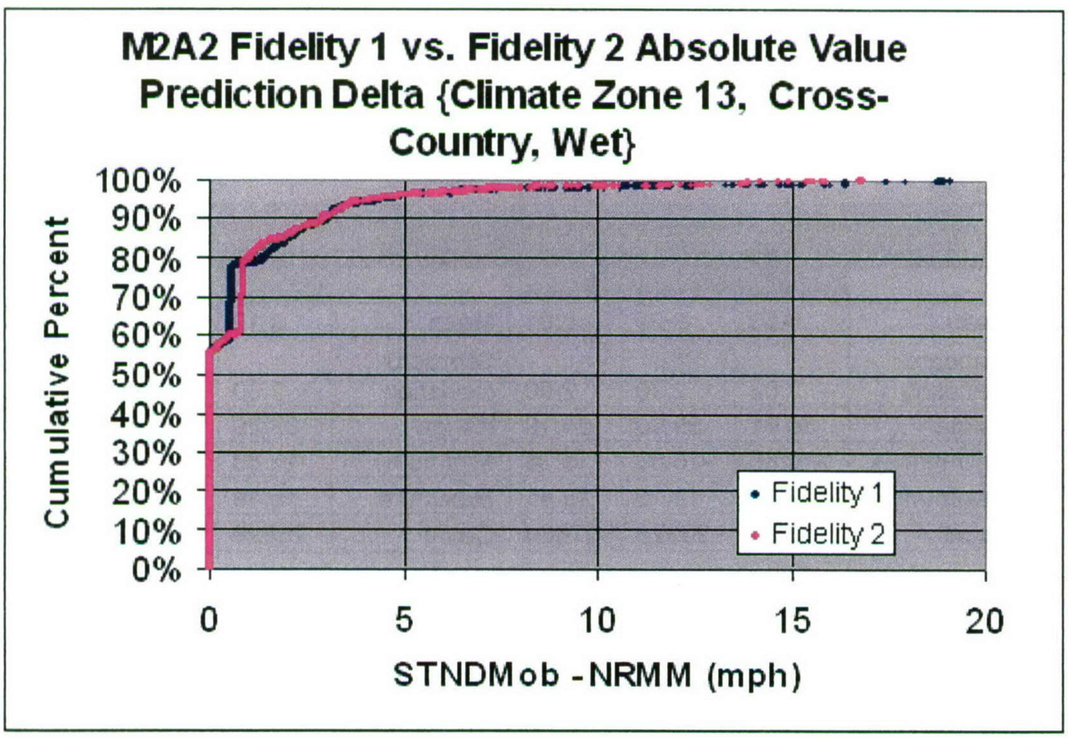


Figure 10. M2A2 Fidelity 1 vs. Fidelity 2 Absolute Value Prediction Delta {Climate Zone 13, Cross-Country, Wet}.

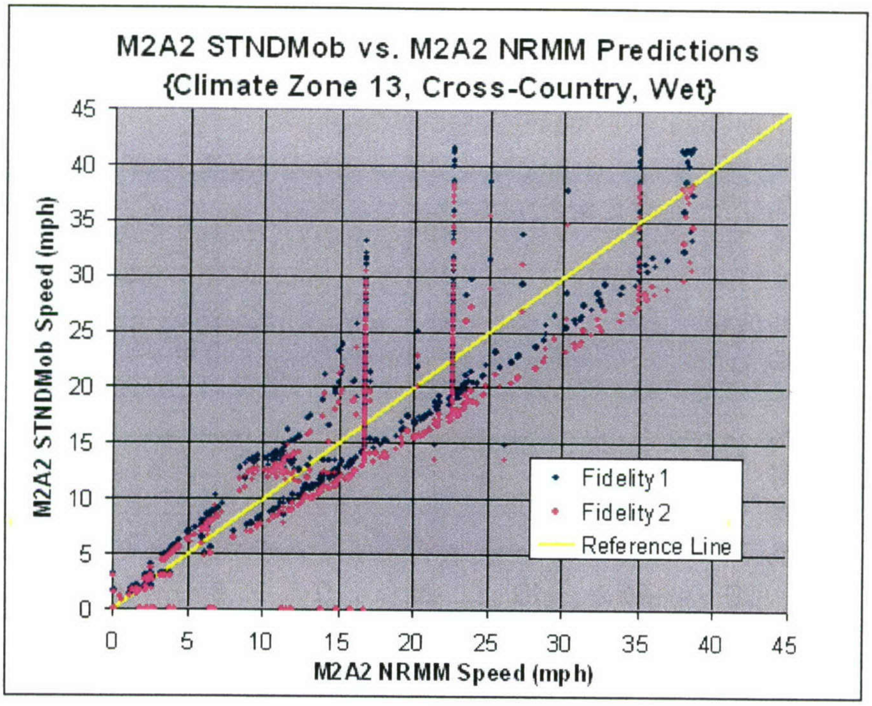


Figure 11. M2A2 STNDMob vs. M2A2 NRMM Predictions {Climate Zone 13, Cross-Country, Wet}.

Cross-Country / Trail – Snow. The final look at the M2A2 on cross-country terrain took into account the affects of snow. The STNDMob speed table includes trails when factoring in snow; thus, the sample population increases to 27,684 as shown in Table 10.

Table 10. M2A2 {Climate Zone 13, Cross-Country, Dry/Wet/Snow}.

Fidelity 1 (STNDMob – NRMM Prediction)				Fidelity 2 (STNDMob – NRMM Prediction)			
	Dry	Wet	Snow		Dry	Wet	Snow
Mean	0.56	0.24	0.81	Mean	0.19	-0.09	0.36
Standard Deviation	3.02	2.70	2.90	Standard Deviation	2.60	2.43	2.44
Range	35.61	35.90	24.19	Range	32.29	32.56	23.39
Minimum	-16.80	-16.80	-5.38	Minimum	-16.80	-16.80	-7.90
Maximum	18.81	19.10	18.81	Maximum	15.49	15.76	15.49
Count	26928	26928	27684	Count	26928	26928	27684

All units are mph except for "Count"

The statistics between the environmental conditions (i.e., Dry, Wet, and Snow) are consistent with two exceptions: "Minimum" and "Range". The Minimum statistic identifies the lowest value calculated when the NRMM speed prediction is subtracted from the STNDMob prediction. It indicates the degree of under-prediction by the STNDMob. The Minimum value for Snow is actually less than that for the Dry and Wet conditions, this in turn reduces the Range value. For the M2A2, this means that the STNDMob Fidelity 1 and 2 speed predictions for snow are closer to the NRMM baseline relative to the Dry and Wet conditions. This variation from the Dry and Wet conditions can be traced to differences in speed predictions due to the snow.

During the Cross-Country/Dry and Wet discussions, it was noted that some under-predictions were occurring due to NRMM indicating mobility for the M2A2 while the STNDMob indicated a NOGO situation using the representative vehicle (i.e., M1A1). This situation was graphically depicted by the data points located along the x-axis of Figure 8 and Figure 11. As you may recall, the STNDMob is using the Bin 1 representative vehicle (i.e., M1A1) as its prediction basis, and, in these cases, the M1A1 was incapable of movement while the M2A2 could still move. In Figure 14, one will observe that these under-predictions are not occurring in the snow conditions. Therefore, since these data points were responsible for the "Minimum" values and "Range," a change as depicted in Table 10 was expected.

The initial theory for the disappearance of these data points was that the M2A2 and the M1A1 were both incapable of movement due to the snow conditions, therefore moving all of these points to the graph origin. Upon closer examination of the data, the exact opposite was the case; both vehicles were mobile. The key factor for the drop in NOGO situations is the reduction in soil resistance due to the frozen ground. On some terrain units within the Dry and Wet environments, the M1A1 cannot move due to soil resistance while the M2A2 can maneuver. Once the ground becomes frozen and snow covered, the M1A1 also becomes mobile.

Figure 12, Figure 13, and Figure 14 show similar trends as previously noted for the Dry and Wet conditions. In the case of Snow conditions, 95 percent of Fidelity 1 and 96 percent Fidelity 2 predictions were within ±5 mph of the NRMM baseline. This is consistent with the STNDMob's predictions in both Dry and Wet environments.

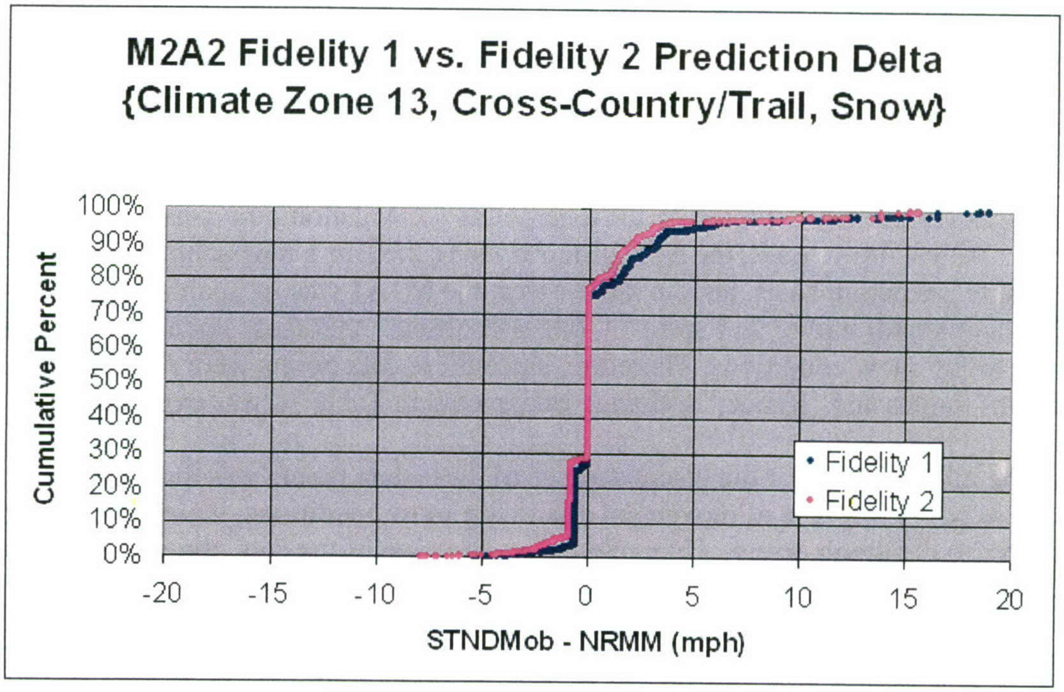


Figure 12. M2A2 Fidelity 1 vs. Fidelity 2 Prediction Delta {Climate Zone 13, Cross-Country / Trail, Snow}.

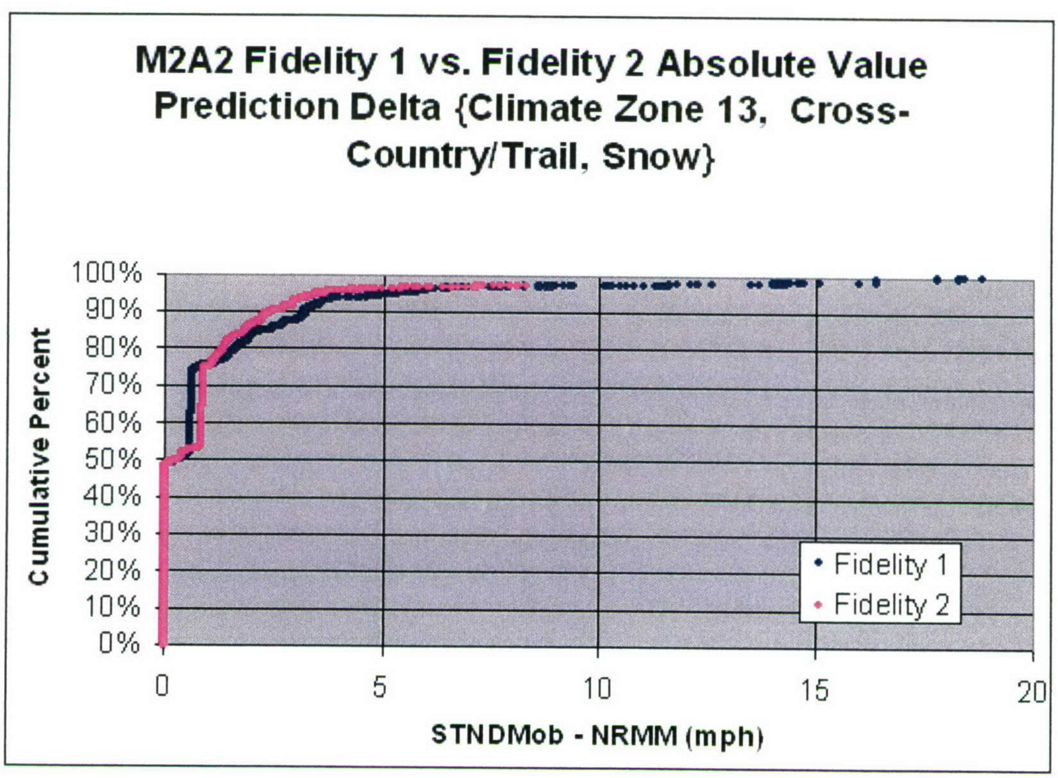


Figure 13. M2A2 Fidelity 1 vs. Fidelity 2 Absolute Value Prediction Delta {Climate Zone 13, Cross-Country / Trail, Snow}.

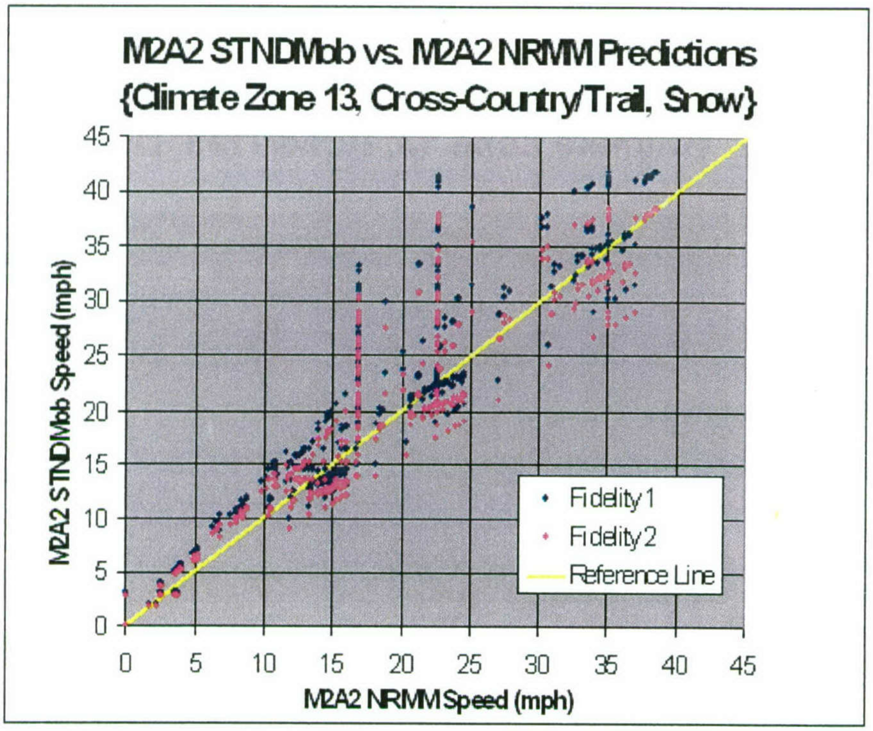


Figure 14. M2A2 STNDMob vs. M2A2 NRMM Predictions {Climate Zone 13, Cross-Country / Trail, Snow}.

Road/Trail – Dry. The remaining sections in 3.1.4 further examine the M2A2, but on road and trail conditions. Table 11 identifies the statistics for the experiment. Differences between the Fidelity 1 and 2 predictions again show the overall shifting of the data after the bin factor is applied. The mean for Fidelity 1 is higher than was experienced in the cross-country cases, but once the bin factor was applied, the mean dropped down to the NRMM baseline (i.e., .05 mph).

Table 11. M2A2 {Climate Zone 13, Road / Trail, Dry}.

Fidelity 1 (STNDMob – NRMM Prediction)		Fidelity 2 (STNDMob – NRMM Prediction)	
	Dry		Dry
Mean	1.79	Mean	0.05
Standard Deviation	2.70	Standard Deviation	2.55
Range	12.94	Range	12.34
Minimum	-5.23	Minimum	-7.71
Maximum	7.71	Maximum	4.63
Count	864	Count	864

All units are mph except for "Count"

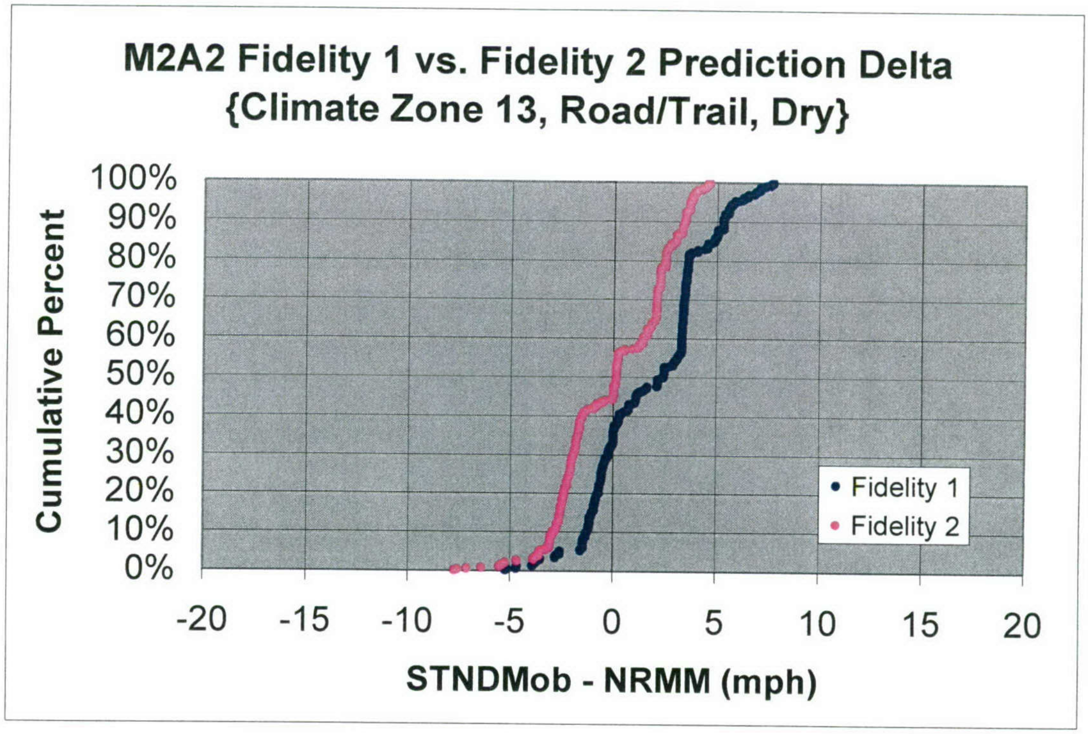


Figure 15. M2A2 Fidelity 1 vs. Fidelity 2 Prediction Delta {Climate Zone 13, Road/Trail, Dry}.

Figure 15 and Figure 16 graph the STNDMob – NRMM prediction deltas for the M2A2 on-roads and trails, dry conditions. The graph is considerably different from the cross-country results shown in Figure 5 and Figure 7. The road and trail data have few NOGO situations, thus causing the significant difference between the cross-country graph and the road/trail graph.

In the case of Dry conditions, 85 percent of Fidelity 1 and 98 percent of Fidelity 2 predictions were within ±5 mph of the NRMM baseline as shown in Figure 16. Fidelity 2 provides a significant benefit, by percent, in reducing the STNDMob – NRMM prediction delta with respect to Fidelity 1. The general benefit is somewhat overstated, since the prediction delta range is 2-3 times smaller for road and trails than for cross-country. For Fidelity 1, 95% of the prediction deltas are within ±6 mph.

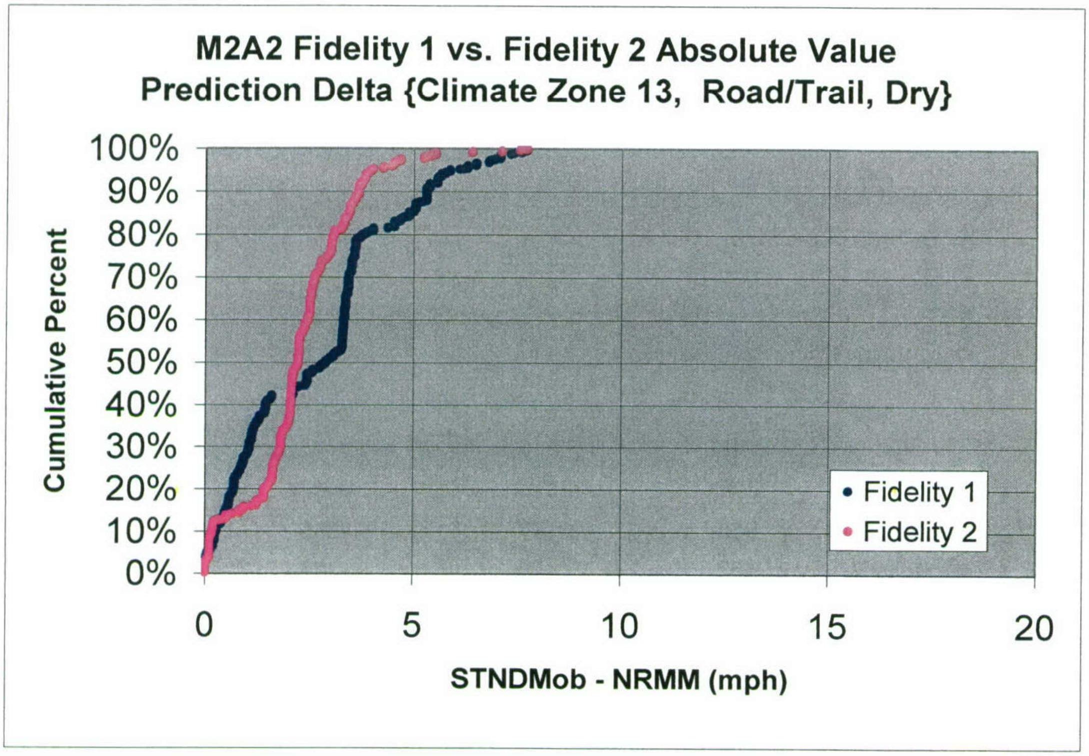
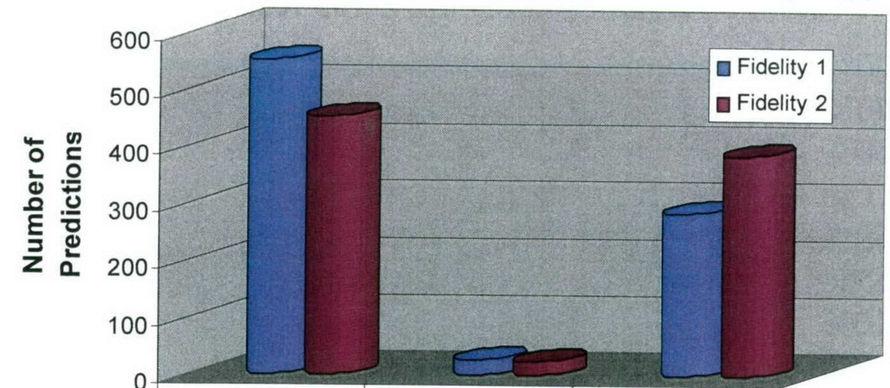


Figure 16. M2A2 Fidelity 1 vs. Fidelity 2 Absolute Value Prediction Delta {Climate Zone 13, Road/Trail, Dry}.

Figure 17 identifies the exact number of over, under, and even-predictions for this dry road case. In the case of the M2A2, there are more over-predictions than under-predictions. When the bin factor is applied, Fidelity 1 has 22.1 percent more over-predictions than Fidelity 2. While Fidelity 2 produced more under-predictions, it also produced fewer over-predictions. Since over-predictions account for the larger speed differences, the overall effect of applying the Fidelity 2 bin factor delivers increased prediction accuracy relative to Fidelity 1. The overall effect can be seen in the mean and standard deviation changes identified in Table 11.

Figure 17 looks significantly different relative to the dry cross-country case, Figure 6. The road case has far fewer even-predictions. The dry cross-country case produced many NOGO predictions by the STNDMob and NRMM; therefore, many even-predictions were made. The road case has very few NOGO situations and, thus, only a few even-predictions.



	Over	Even	Under
Fidelity 1	552	27	285
Fidelity 2	452	24	388

Figure 17. M2A2 STNDMob Over / Even / Under-Predictions {Climate Zone 13, Road/Trail, Dry}.

The scatter plot for the road/trail speed-made-good predictions in a dry environment is shown in Figure 18. It shows the downward shift of the data points to the NRMM baseline once the bin factor is applied. Three areas of clustering can be noted. As was discussed earlier in the report, NRMM uses speed limiting factors (e.g., shock, visibility, ride) to limit the vehicle speed under certain environmental conditions. With Figure 8, the limiting factor was based on the amount of energy transferred to the driver (i.e., ride). This limiting factor impacts all of the cross-country conditions.

A similar situation exists regarding the road and trail simulations. Since roads and trails have less surface roughness relative to cross-country conditions, vehicle ride is not the limiting factor. Due to the faster speeds that may be obtained, "visibility" becomes the limiting factor for roads and trails. Visibility is one of the environmental conditions that is input to NRMM and STNDMob. For the STNDMob Fidelity 1 and 2, there are four standard visibility distances, 25, 50, 100, and 300 feet. The NRMM braking sub-model determines the maximum permissible vehicle speed that allows a controlled stop within the available visibility. The situation in which a vehicle cannot stop while traveling down a slope is considered a NOGO condition.

Upon examination of the M2A2's NRMM runs, for 25 feet visibility the maximum permissible speed was ~15 mph, for 50 feet visibility the speed was ~22 mph, and for 100 feet visibility the speed was ~35 mph. There were no instances for which speed was limited by visibility when the visibility was set at a distance of 300 feet. This indicates that the clustering on Figure 18 is caused by speed limitations related to visibility and braking distance on various terrain types. Also of note is the elongated

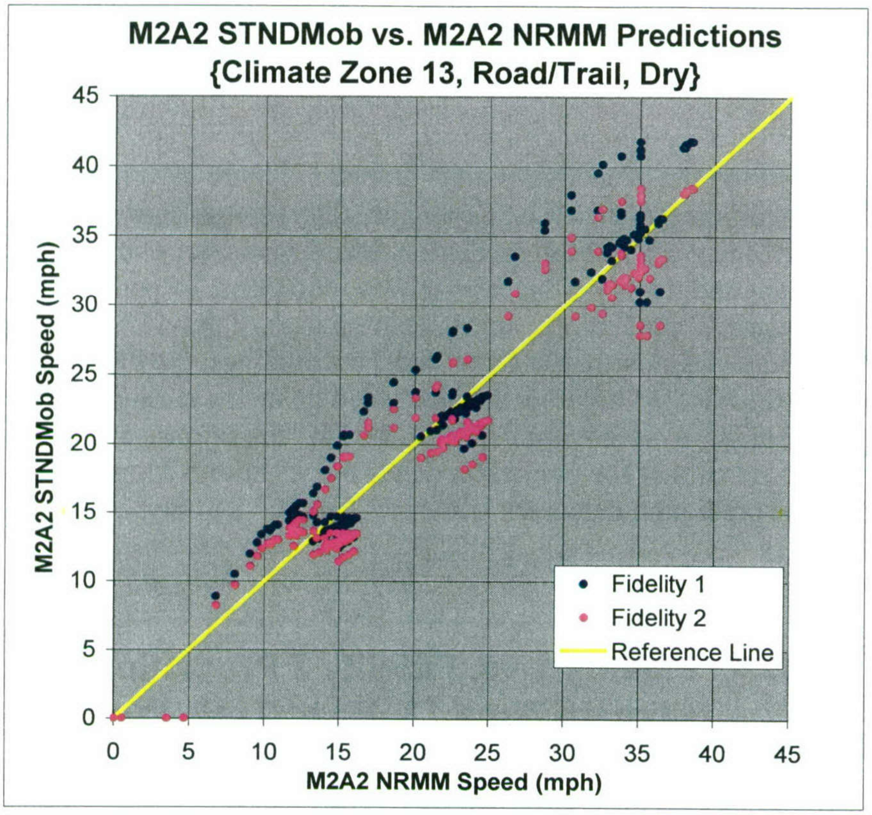


Figure 18. M2A2 STNDMob vs. M2A2 NRMM Predictions {Climate Zone 13, Road/Trail, Dry}.

shape of the clusters. This is caused by the NRMM predicted speed being greater than than the STNDMob predicted speed (i.e., an under-prediction by the STNDMob). As you may recall, the NRMM predicted speed uses the M2A2 to make the speed prediction while the STNDMob uses the M1A1 to represent the M2A2. The M1A1, being a much larger vehicle, requires a slower speed to brake safely on a given terrain, thus causing the elongated shape.

Road/Trail – Wet. In order to further compare STNDMob Fidelity 1 and 2 predictions to the NRMM baseline, the procedures previously described in Road / Trail – Dry conditions were again performed; this time in a Wet environment.

Table 12 identifies the statistics for the two conditions (i.e., Dry and Wet).

Table 12. M2A2 {Climate Zone 13, Road/Trail, Dry/Wet}.

Fidelity 1 (STNDMob – NRMM Prediction)			Fidelity 2 (STNDMob – NRMM Prediction)		
	Dry	Wet		Dry	Wet
Mean	1.79	0.72	Mean	0.05	-0.84
Standard Deviation	2.70	3.62	Standard Deviation	2.55	3.57
Range	12.94	13.52	Range	12.34	12.83
Minimum	-5.23	-5.81	Minimum	-7.71	-8.20
Maximum	7.71	7.71	Maximum	4.63	4.63
Count	864	864	Count	864	864

All units are mph except for "Count"

There were minor differences in the statistics (e.g., increased standard deviation in the Wet environment), but, generally, the prediction deltas from Dry to Wet conditions were similar.

Comparing the Wet environment graphics (Figure 19, Figure 20, and Figure 21) to the Dry condition graphics (i.e., Road/Trail, Dry) shows similar results. This indicates that the NRMM and STNDMob prediction delta is consistent between Dry and Wet environmental conditions. In the case of Wet conditions, 84 percent of Fidelity 1 and 83 percent of Fidelity 2 predictions were within ±5 mph of the NRMM baseline. While the Fidelity 1 results are close to the Dry Road/Trail findings, the Fidelity 2 results are further from the NRMM baseline than expected given the earlier results that 98 percent of Fidelity 2 predictions were within ±5 mph for Dry conditions. For Wet conditions, Fidelity 1, 95 percent of the prediction deltas are within ±5.7 mph, and, for Fidelity 2, 95 percent of the prediction deltas are within ±7.1 mph.

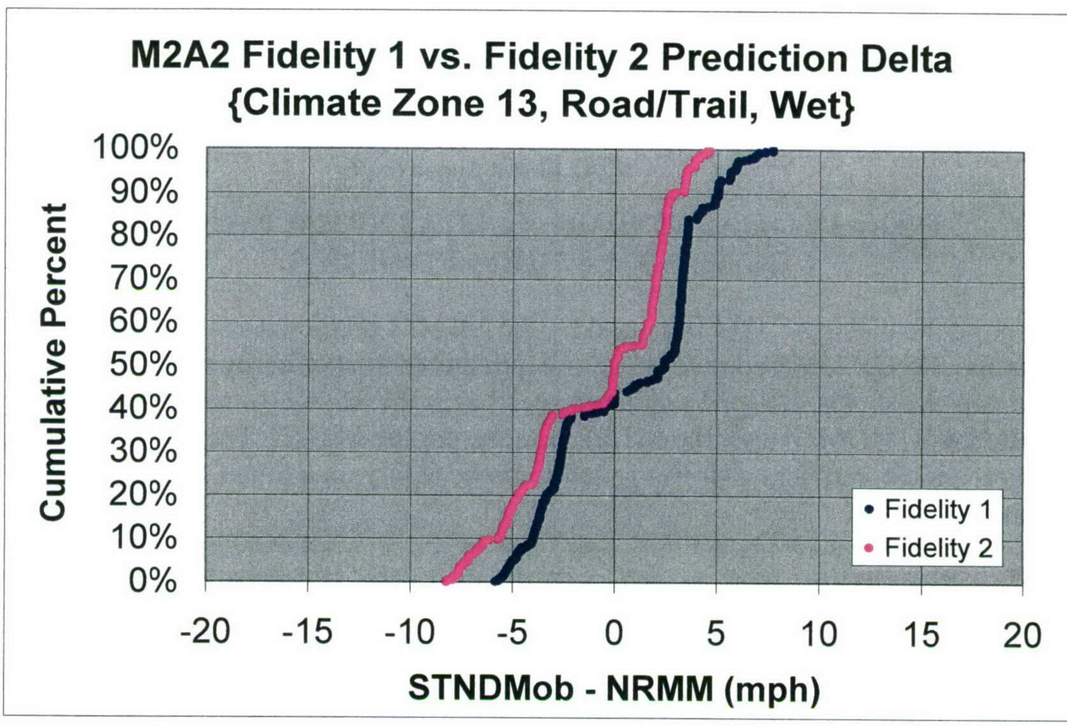


Figure 19. M2A2 Fidelity 1 vs. Fidelity 2 Prediction Delta {Climate Zone 13, Road/Trail, Wet}.

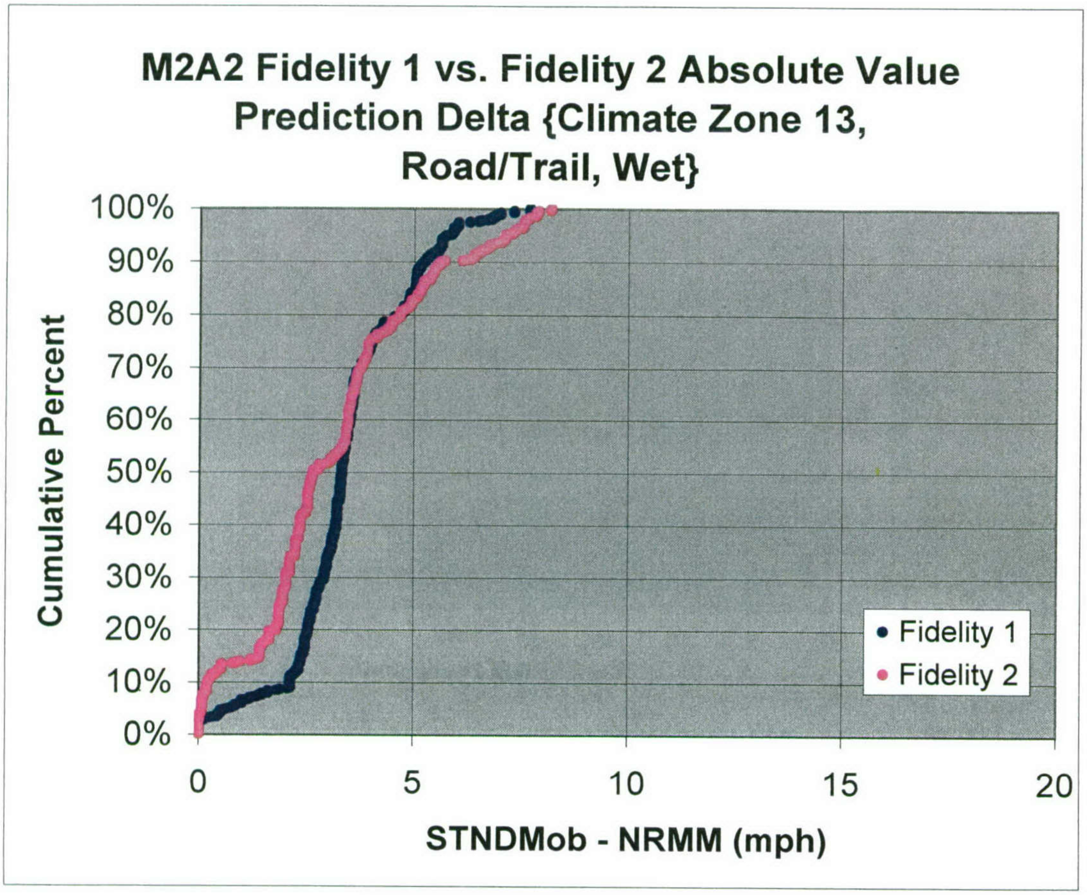


Figure 20. M2A2 Fidelity 1 vs. Fidelity 2 Absolute Value Prediction Delta {Climate Zone 13, Road/Trail, Wet}.

The clustering caused by visibility and braking limitations, as seen with the Road and Trail graph, Dry condition, on Figure 18, can be seen again in Figure 21, and is actually more evident with the Wet conditions,. This is an indication that the speed required to safely brake is growing further apart between the M2A2 and the M1A1 for a wet surface condition.

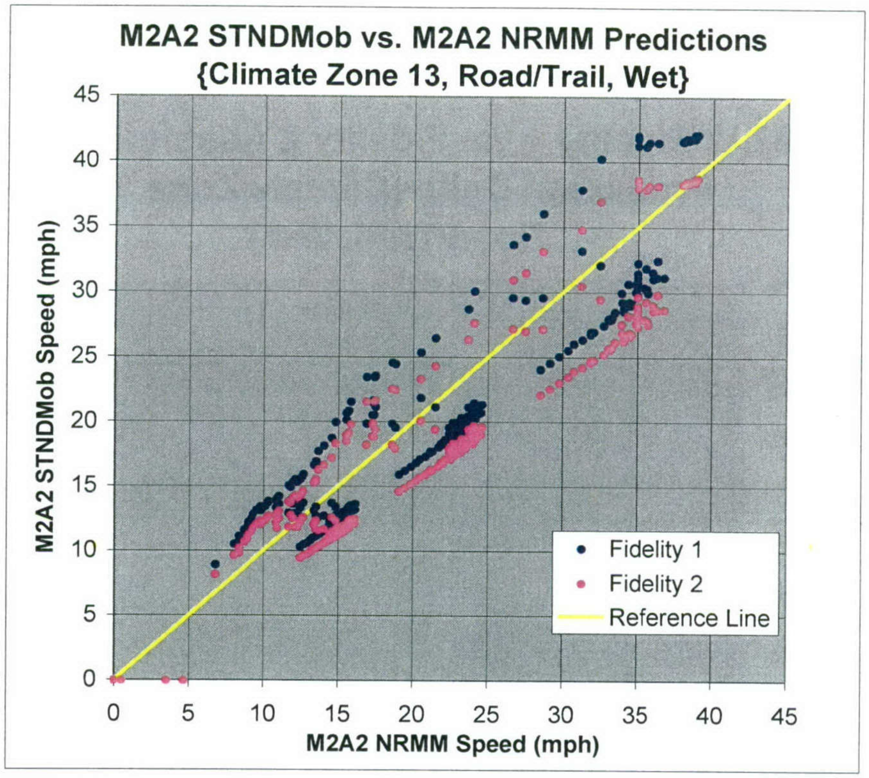


Figure 21. M2A2 STNDMob vs. M2A2 NRMM Predictions {Climate Zone 13, Road/Trail, Wet}.

Road – Snow. The final Bin 1 examination addresses Fidelity 1 and 2 predictions for the M2A2 on the road in snow conditions. This data set is unique since the two previous conditions examined road and trail conditions together, but this experiment excluded trails conditions. Roads are considered plowed after the accumulation of four inches of snow while trails are not plowed. Roads are, thus, considered a separate case.

Table 13 identifies the statistics for the M2A2 on a road with snow conditions. Since the data set does not include trail data, the sample population is considerably smaller relative to the Dry and Wet conditions.

Table 13. M2A2 {Climate Zone 13, Road/Trail, Dry/Wet/Snow}.

Fidelity 1 (STNDMob – NRMM Prediction)				Fidelity 2 (STNDMob – NRMM Prediction)			
	Dry	Wet	Snow		Dry	Wet	Snow
Mean	1.79	0.72	1.75	Mean	0.05	-0.84	-0.18
Standard Deviation	2.70	3.62	2.64	Standard Deviation	2.55	3.57	2.45
Range	12.94	13.52	8.91	Range	12.34	12.83	8.21
Minimum	-5.23	-5.81	-1.58	Minimum	-7.71	-8.20	-3.58
Maximum	7.71	7.71	7.33	Maximum	4.63	4.63	4.63
Count	864	864	108	Count	864	864	108

All units are mph except for "Count"

Comparing the graphs from the Dry, Wet, and Snow conditions (Figure 22, Figure 23, and Figure 24) to the earlier Road/Trail; Dry & Wet conditions shows that the NRMM and STNDMob prediction delta is consistent between Dry, Wet, and Snow environmental conditions. In the case of Snow conditions, 88 percent of Fidelity 1 and 100 percent of Fidelity 2 predictions were within ±5 mph of the NRMM baseline. For Snow conditions, Fidelity 1, 95 percent of the prediction deltas are within ±6.8 mph.

As with the Dry and Wet conditions for Road and Trails, Figure 18 and Figure 21, respectively, the clustering caused by visibility and braking limitations are still evident, Figure 24.

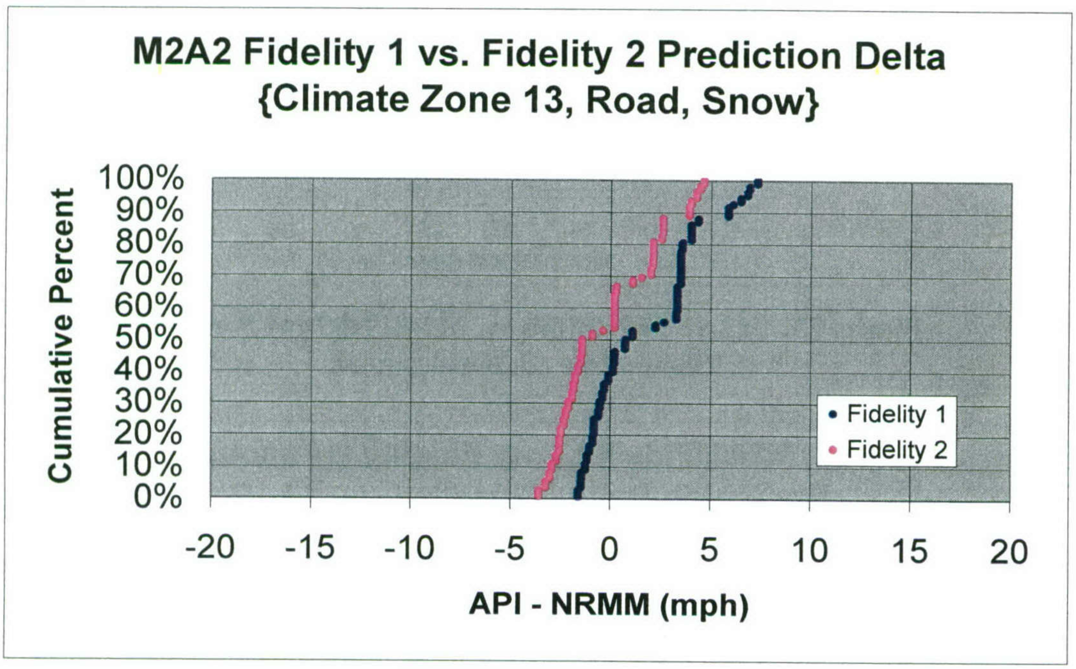


Figure 22. M2A2 Fidelity 1 vs. Fidelity 2 Prediction Delta {Climate Zone 13, Road, Snow}.

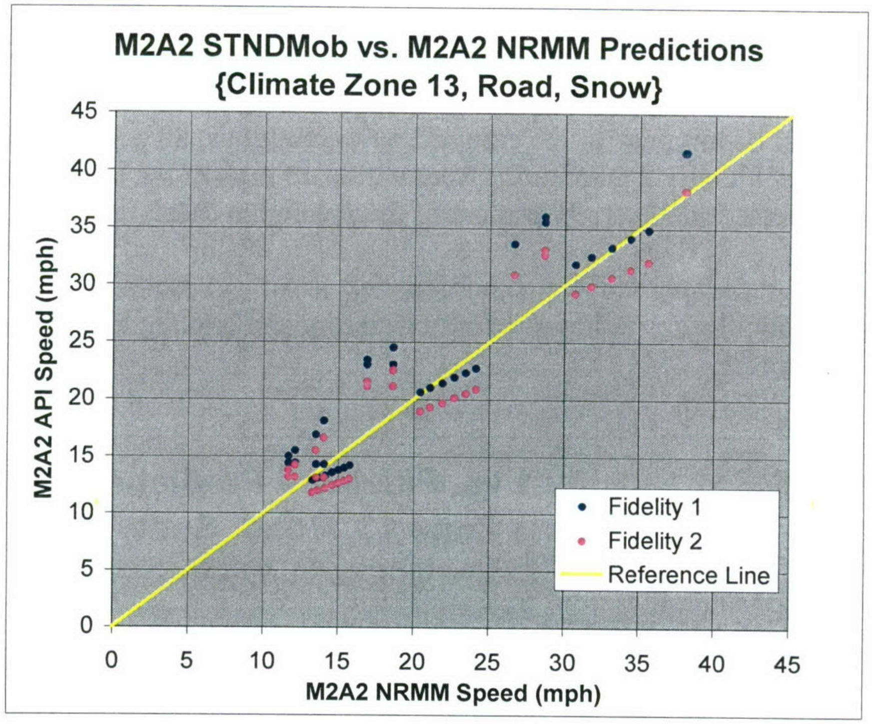


Figure 23. M2A2 STNDMob vs. M2A2 NRMM Predictions {Climate Zone 13, Road, Snow}.

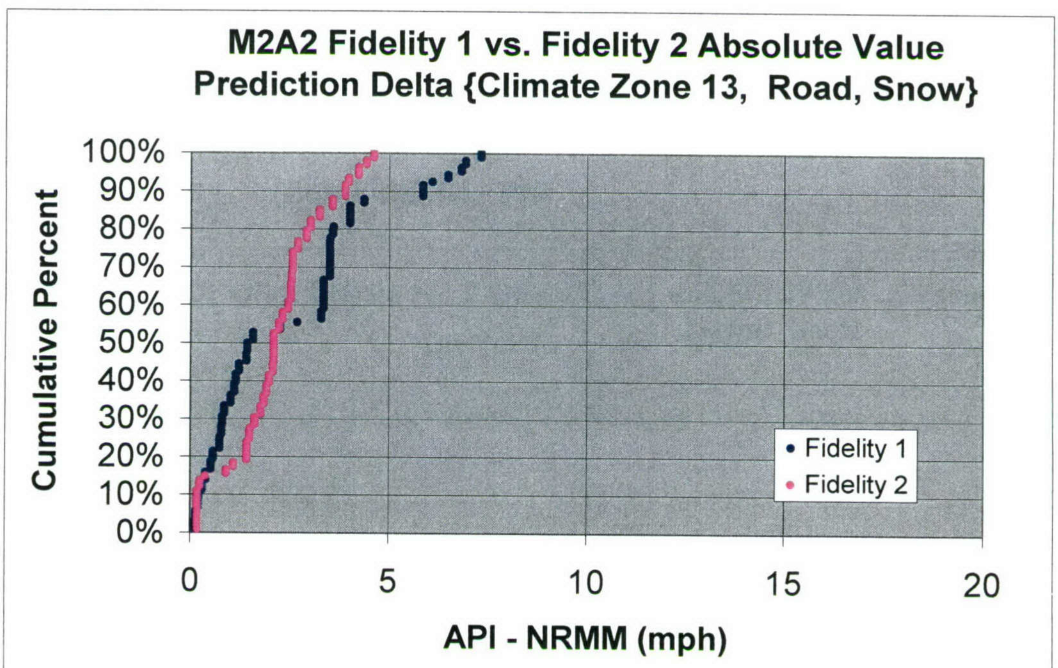


Figure 24. M2A2 Fidelity 1 vs. Fidelity 2 Absolute Value Prediction Delta {Climate Zone 13, Road, Snow}.

3.5 Question #5 – Are the values used to describe vehicles within STNDMob accurate?

Methodology – STNDMob contains a file called VehicleTypeIDMap.xml that is used to track the bin number and bin factor as well as the swimming and fording speeds for all vehicles available in STNDMob. The file also contains information such as weight, maximum speed, power, and gradient that are not used during the model runs for Fidelity 1 and 2 but were used in the original development of the bin factors. The equation used to calculate the bin factors can be found in Section 2.2.2 of this report. The full methodology for placing vehicles in bins can be found in ERDC/GSL TR-02-21 (Ref. 4).

In an effort to ensure that the correct bin values and bin factors were calculated, AMSAA manually checked a sample of bin factors and associated values for accuracy since the vehicle list was too large for a complete review. Also, because there are multiple sources for the values contained within the file (Test Reports, NRMM Vehicle Files, Manufacturer Data Sheets, etc.), a comparison was made to several of the sources to determine if the values chosen were representative.

Results – In the discussions below, several references are made to data that were within the "expected ranges." Due to multiple variants of vehicles, varied payloads, and other potential variations, deciding on one specific value for speed, weight, or any of the other variables is not possible. Therefore, each value was examined and determined to be "within the expected ranges" through comparison to other sources. As mentioned previously, these sources consisted of NRMM vehicle files, Manufacturer Data Sheets, Test Reports, Jane's Defense Resources, and even websites containing vehicle specific data. For example, the Bin 4 vehicle (M1084/MTV) loaded weight in the VehicleTypeIDMap.xml is 15,078 kg. A test report listed the weight at 15,463 kg while the manufacturer tech sheet lists the curb weight as 10,740 kg. Because the weight in the VehicleTypeIDMap.xml file was within this range, it was considered acceptable.

Fidelity 1 requires that every vehicle be placed in the appropriate bin so that the representative speed for that bin can be used. Therefore, the "bin" value contained within the VehicleTypeIDMap.xml must be correct so that the most appropriate speed can be used. As expected, it was determined that all twelve of the representative vehicles were correctly labeled in the file. Of the remaining 102 vehicles in the file, 30 were randomly chosen for review. This review consisted of checking the data in the VehicleTypeIDMap.xml file and then exercising these values using the binning methodology to insure that they had the correct bin values associated with them. This check also required a review of the values associated with each vehicle that were pertinent to the binning methodology. All values were within the expected ranges. Again, all 30 vehicles had been binned as described in the methodology report.

Fidelity 2 adds the additional requirement that each vehicle have a bin factor associated with it. As explained previously, this bin factor is used to adjust the bin speed to produce a vehicle-specific speed and, thus, a higher fidelity. Because the bin factor is based solely on the ratio of the specific vehicle's maximum road speed to the representative vehicle's maximum road speed, it was only necessary to perform a check on the maximum road speeds. The use of accurate road speeds ensured that the methodology was being followed correctly. A check of the same vehicles discussed for Fidelity 1 produced similar results. All vehicles investigated had maximum road speeds within the ranges expected.

3.6 Question #6 – Do each of the twelve STNDMob bins represent a well-defined vehicle class for use in categorizing vehicles in STNDMob Fidelity 1 and Fidelity 2?

Methodology – This question arose during the validation of STNDMob because, in several cases, it appeared that the speeds produced for one bin matched closely with other bins. It was determined that an investigation should be performed to determine whether each vehicle bin added value to the STNDMob program.

To perform this check, it was necessary to compare the NRMM speed predictions produced by each of the twelve bin vehicles across widely varying terrains. The NRMM speed difference between the various vehicles was the examined metric.

NRMM Speed Difference = | *Vehicle 1 NRMM Speed Prediction – Vehicle 2 NRMM Speed Prediction* |

Due to the number of possible terrain scenarios, a limited check was performed. All twelve bin vehicles were run in NRMM on six different terrains that are described as follows:

- **13CD300A** Climate Zone 13, Cross-Country, Dry, 300 ft Visibility, 150 ft Obstacle Spacing
- **6CD50B** Climate Zone 6, Cross-Country, Dry, 50 ft Visibility, 30 ft Obstacle Spacing
- **8CD100A** Climate Zone 8, Cross-Country, Dry, 100 ft Visibility, 150 ft Obstacle Spacing
- **13CW300A** Climate Zone 13, Cross-Country, Wet, 300 ft Visibility, 150 ft Obstacle Spacing
- **8CS300A** Climate Zone 8, Cross-Country, Snow, 300 ft Visibility, 150 ft Obstacle Spacing
- **4RD300A** Climate Zone 4, Road, Dry, 300 ft Visibility, 150 ft Obstacle Spacing

These terrains represented Dry, Wet, and Snow conditions for which there were maximum visibility and obstacle spacing. Obstacles were limited because when obstacles are introduced, the speeds quickly converge to zero for all of vehicles. This convergence makes it appear that the bins all have similar speeds. The same is true for limited visibility terrain. Therefore, limited visibility and close obstacle spacing was avoided for this investigation.

Results – Running NRMM with the twelve vehicles and six terrain types produced 11,691 predictions per vehicle (140,292 total speed predictions). Each vehicle speed, on each terrain unit, was compared to the corresponding speed for all other vehicles. For example, the speed for the Bin 1 vehicle on terrain 13CD300A, terrain unit 1, was compared to the Bin 2 - 12 vehicles on terrain 13CD300A, terrain unit 1. The same was done for all of the other terrain units on 13CD300A. The other five terrains types were then tested in a similar fashion. For each vehicle pairing, the absolute value of the speed prediction delta was averaged across all terrain units to quantify the overall difference between each vehicle pairing. In addition, the standard deviation of these speed differences was computed to quantify how well the average difference characterized the data set.

An example of this result can be seen in Figure 25. The comparison shows the speed difference between the Bin 1 (M1A1) and the Bin 12 (Unmanned ATV - Kawasaki). If the vehicles were representative of each other, the data points would mainly lie along the x-axis indicating that the difference in speeds is approximately zero. As expected though, the M1A1 and the Kawasaki are significantly different and their speeds do not match well, producing a fairly scattered plot. There is an 11.19 mph average difference in speed between the Kawasaki and M1A1 over this terrain. The standard deviation of the speed difference for these vehicles is 7.93. A similar analysis was performed with similar results on five additional terrains. Results of these analyses can be viewed in Appendix B.

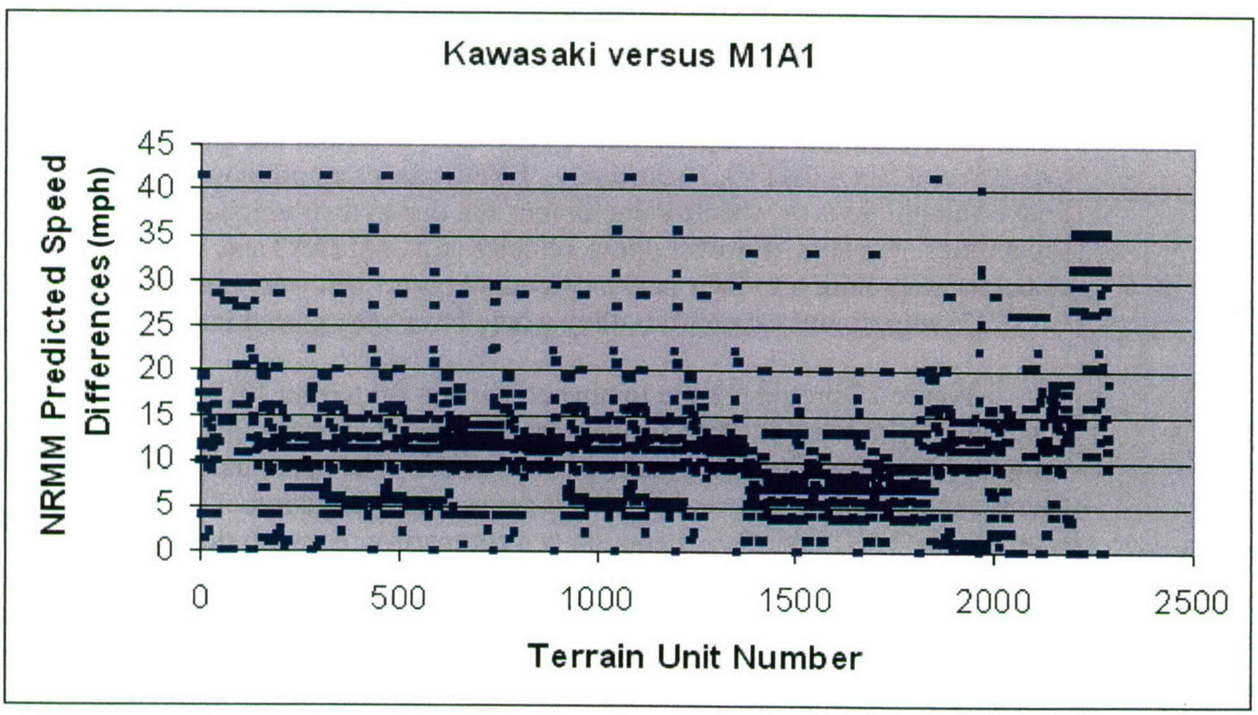


Figure 25. Bin 1 (M1A1) vs. Bin 12 (Unmanned ATV - Kawasaki) Comparison, Terrain: 13CD300A.

In comparison, Figure 26 shows a LAV25, Bin 11, compared to a Medium Tactical Vehicle (MTV), Bin 4. The differences between the NRMM speed predictions for these vehicles are quite small. The average difference, on terrain 13CD300A, is only 1.23 miles per hour with a standard deviation of 1.99.

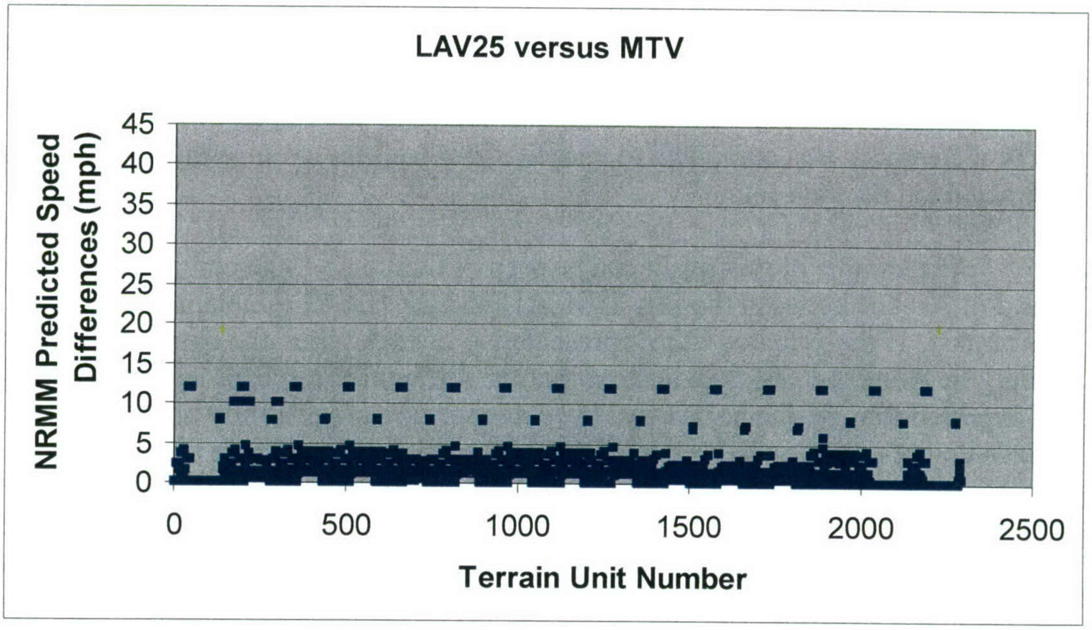


Figure 26. Bin 4 (MTV) vs. Bin 11 (LAV25) Comparison; Terrain: 13CD300A.

After this analysis was performed on the six terrain types and twelve vehicles, it was determined that the binning methodology does represent distinct classes for most vehicles. Bin 10 (M113A2) and Bin 11 (LAV25), however, are quite similar to Bin 2 (MLRS) and Bin 4 (MTV), respectively. ERDC places amphibious vehicles into either a tracked/amphibious or wheeled/amphibious bin due to their unique water mobility capabilities. On land, however, these vehicles (e.g., M113A2 and LAV25) have mobility characteristics similar to their land only counterparts. If it were not for the M113A2 and LAV25's amphibious capabilities, they would have been placed into Bin 2 and Bin 4.

Figure 27 provides a bin to bin comparison for terrain 13CD300A in dry conditions. The chart shows a comparison for every bin representative vehicle as compared to every other bin representative vehicle. The upper half of the chart shows average error while the lower half shows the standard deviation of the errors. For example, the two highlighted items show a comparison between the MLRS and M113A2 as well as the MTV and the LAV25. There is a 1.97 mph average absolute difference in speed between the MLRS and M113A2 over this terrain. The standard deviation for these vehicles is 1.63. A similar analysis was performed with comparable results on five additional terrains.

Average Prediction Delta (mph)

Bin 1 (M1A1)	7.26	9.84	10.71	12.42	15.51	10.71	13.97	16.90	8.51	9.37	11.19
Bin 2 (MLRS)		3.71	5.25	7.11	9.69	5.25	8.18	11.08	1.97	5.20	10.56
Bin 3 (AVLB)			3.30	5.22	6.16	3.30	4.69	7.38	2.82	4.79	13.79
Bin 4 (MTV)				3.12	6.24	2.41	4.83	7.63	3.72	1.23	12.79
Bin 5 (M985-10)					3.18	4.58	1.77	4.57	6.09	3.67	15.82
Bin 6 (M917)						5.33	2.07	1.81	8.52	6.54	18.86
Bin 7 (MTVM1095)							3.60	6.36	4.22	3.29	13.92
Bin 8 (M985M989)								2.95	7.03	5.17	17.31
Bin 9 (M911M747)									9.88	7.92	20.21
Bin 10 (M113A2)										4.37	11.75
Bin 11 (LAV25)											12.52
Bin 12 (Kawasaki ATV)											

Predicted Delta Standard Deviation

Bin 1 (M1A1)	7.67	7.67	9.57	12.66	13.54	9.57	11.89	12.98	7.34	11.22	7.93
Bin 2 (MLRS)		3.11	6.09	7.16	8.09	6.09	6.83	7.55	1.63	6.14	6.65
Bin 3 (AVLB)			5.23	5.67	7.31	5.23	6.03	6.73	3.28	5.37	7.36
Bin 4 (MTV)				4.28	5.92	3.80	4.58	6.39	6.17	1.99	7.64
Bin 5 (M985-10)					3.40	4.50	2.94	4.13	6.85	4.19	7.78
Bin 6 (M917)						6.55	2.59	2.46	8.04	5.77	8.51
Bin 7 (MTVM1095)							4.65	6.77	6.38	4.08	8.33
Bin 8 (M985M989)								2.80	6.81	4.63	7.92
Bin 9 (M911M747)									7.45	6.51	8.72
Bin 10 (M113A2)										6.29	6.54
Bin 11 (LAV25)											7.74
Bin 12 (Kawasaki ATV)											

Figure 27. Average NRMM Speed Differences and Standard Deviations for Terrain 13CD300A (mph)

Due to the small prediction delta averages and corresponding standard deviations (highlighted in green), this calls into question the necessity of having two separate bins strictly for amphibious vehicles. This creates a situation where an amphibious vehicle, having different mobility characteristics relative to the M113A2 or LAV25, would have its mobility characteristics misrepresented because it is binned within a generic amphibious category. The impact of this is not quantifiable since it is situation dependent. For the case of a high mobility tracked vehicle (e.g., M1A1) that is also amphibious, the average error in speed prediction is 8.5 mph since the "amphibious M1A1" is being represented by an M113A2 simply because it is amphibious.

3.7 Question #7 – Does STNDMob handle vehicle fording and swimming situations?

Methodology – As discussed in Section 2.2.1, STGJ codes are sent to the STNDMob and then converted to MLU codes. This is true except for a few STGJ codes that represent areas of water. When an STGJ code representing water is input, STNDMob will return a swimming or fording speed. To evaluate if this procedure is working as designed, STNDMob was sent STGJ codes representing water areas to determine if the correct speeds were returned.

Result – STNDMob identifies the following STGJ codes as **fording** areas:

- 114-149
- 152-162
- 200-209
- 225-235

STNDMob identifies the following STGJ codes as **swimming** areas:

- 761-771

AMSAA selected the twelve bin representative vehicles and the entire set of 102 non-representative vehicles to determine if the returned fording and swimming speeds were correct. The VehicleTypeIDMap.xml file lists whether a vehicle can ford and/or swim. The results were manually compared against VehicleTypeIDMap.xml to assure accuracy. If the vehicle can ford the body of water, then the predicted speed is 8 kph (5.0 mph). Within STNDMob, fording capability is defined as being able to traverse a body of water greater than .75 m in depth. If the vehicle can swim the body of water, then the predicted speed is 10 kph (6.2 mph). ERDC indicated that the fording and swimming speeds used were reasonable estimates based on NRMM II vehicle files, Janes Military Information texts, and Aberdeen Test Center test results. While a single speed was used to represent fording operations, ERDC points out that fording speed is actually a function of fording depth. During fording operations, deeper water requires slower travel speeds to prevent unwanted flooding. For example, the Stryker can ford at 8 kph at 1.7 m or 11 kph at 1.3 m. This level of detail was not considered required for STNDMob Fidelity 1 and 2.

The results for the twelve representative vehicles can be viewed in Table 14. All fording and swimming STGJ codes were evaluated. The outcome for the Fidelity 1 and Fidelity 2 representative vehicle examination was as expected. The STNDMob Fidelity 1 and 2 fording and swim speed predictions were consistent with the VehicleTypeIDMap.xml file.

Table 14. Fidelity 1 and 2 Representative Bin Vehicle Fording and Swimming Speeds (mph).

Bin Number	Representative Bin Vehicle	Fording Speed (mph)	Swim Speed (mph)
1	M1A1	5.0	0
2	M270 MLRS	5.0	0
3	M60 AVLB	5.0	0
4	M1084 MTV	5.0	0
5	M985 HEMTT	5.0	0
6	M917 Dump Truck	0	0
7	M1084/M1095	5.0	0
8	M985/M989	5.0	0
9	M911/M747 HET	5.0	0
10	M113A2	5.0	6.2
11	LAV25	5.0	6.2
12	Unmanned ATV	0	0

For non-representative vehicles, the results require more explanation. For Fidelity 1, the fording and swimming speeds are pulled from the representative vehicle, not the vehicle's specific entry in the VehicleTypeIDMap.xml file. This is by design since Fidelity 1 results are always based on their representative vehicle. This produces some interesting results since the fording and swimming characteristics of a specific vehicle do **not** always match that of the representative vehicle. There are 102 non-representative vehicles in the VehicleTypeIDMap.xml file, 21 of which produced fording and swimming results that were inconsistent with the specific vehicle. These instances are depicted in Table 15 (differences between File Value and STNDMob Prediction highlighted). Fidelity 2 results, as expected, depicted no inconsistencies.

Table 15. Fidelity 1 Non-Representative Vehicles That Had Fording and Swimming Characteristics Different Than Their Representative Vehicle.

Non-Representative Vehicle, Vehicle #, Representative Bin #	VehicleTypeIDMap.xml File Value		STNDMob Prediction	
	Fording Speed (mph)	Swim Speed (mph)	Fording Speed (mph)	Swim Speed (mph)
BAZ-135L4/FROG, 141, 5	0	0	5.0	0
Hanyang HY473A, 173, 9	0	0	5.0	0
ICV-Stryker, 213, 11	5.0	0	5.0	6.2
KRAZ 214, 149, 6	5.0	0	0	0
KRAZ 260V, 154, 6	5.0	0	0	0
M1074/PLS, 160, 6	5.0	0	0	0
M35A2, 159, 6	5.0	0	0	0
M915A2, 170, 8	0	0	5.0	0
M916A1, 168, 8	0	0	5.0	0
MAZ543A, 150, 6	5.0	0	0	0
Mercedes-Benz 3850, 176, 9	0	0	5.0	0
MK48/14, 157, 6	5.0	0	0	0
Oshkosh M1070, 175, 9	0	0	5.0	0
RM70, 152, 6	5.0	0	0	0
TAM 150 T11, 158, 6	5.0	0	0	0
UAZ469, 134, 4	0	0	5.0	0
URAL 375/SA-4 Reload, 153, 6	5.0	0	0	0
ZIL 131, 155, 6	5.0	0	0	0
ZIL 135/FROG7, 142, 5	0	0	5.0	0
ZIL 157, 151, 6	5.0	0	0	0
ZTS 152, 156, 6	5.0	0	0	0

Given the inconsistencies depicted in Table 15, ERDC may wish to reconsider the fording and swimming logic used for Fidelity 1. It may be beneficial to simply pull the speeds directly off the VehicleTypeIDMap.xml file for the specific vehicle, as is the case for Fidelity 2, to assure proper fording and swimming characteristics are selected. If the User is interested in a vehicle's fording and swimming characteristics, the simplest work around would be for the User to use Fidelity 2 predictions and avoid Fidelity 1. In any event, the User should be made aware of the nuances regarding fording and swimming speed predictions.

Also of interest is how one defines fording. Any vehicle can ford given that the water is shallow enough, thus fording speed is dependent up fording depth. Within STNDMob, if the fording depth for a vehicle is 0.75 m or less, as determined by ERDC, then the vehicle was coded within the VehicleTypeIDMap.xml file as not capable of fording. If the vehicle could ford 0.75 m or more, then the vehicle was given an 8 kph fording speed and coded as such in the VehicleTypeIDMap.xml file. This depth of 0.75 m is near the threshold for what is considered shallow water as specified in many National Ground Intelligence Agency terrain data models. Rather than indicating that every vehicle could ford at least some water, ERDC took this conservative approach to define fording. Swimming is more straightforward as a vehicle can either swim or not swim.

3.8 Question #8 – What are the known limitations associated with using STNDMob Fidelity 1 and Fidelity 2 results?

Methodology – No specific test was performed to address this question. The result was based on a holistic view of the validation.

Result – Fidelity 1 and 2 speed predictions usually produced a large percentage of estimates that were within ±5 mph of the NRMM predictions. This accuracy was considered sufficient for "low resolution" estimates. The User should note, however, the following limitations when using the STNDMob:

- The use of a surrogate vehicle to predict the speed of another vehicle will have associated error. Section 3 of this validation attempts to quantify those errors for Fidelity 1 and 2. One should note that some of the larger errors (i.e., prediction deltas) occur at the extreme range of a vehicle's operating window, as is the case when a vehicle is put into a NOGO situation due to slope and an interpolation is required for the prediction. An example of this is described at the end of Section 3.1.3

- The use of Fidelity 1 for predicting the fording speed of specific vehicles may produce unreasonable predictions given the current assumptions for water depth. Fidelity 2 is the better choice when specific vehicle fording speeds are of interest.

- NRMM speed limiters (e.g., visibility distance, braking distance, maximum tire speed, and vehicle ride) can have a dramatic impact on predicted vehicle speed. NRMM and Fidelity 1 and 2 traditionally use these limiters when making a prediction.

The validated speed tables for Fidelity 1 and 2 were created using the traditional NRMM speed limiters. For example, maximum tire speed limits the speed a vehicle may travel to assure that the tires don't overheat. This limitation is based on one hour of constant driving at this speed. The burst speed for the vehicle could potentially be higher. A User attempting to simulate a burst speed could be given a prediction that is too low for the given terrain and situation. This is more likely a concern for real-time simulators than for combat effectiveness models. If the User wishes instantaneous speed predictions, then the use of Fidelity 1 and 2 should be avoided. Section 2.1, in addition, offers a discussion related to intended use of the STNDMob tool.

4. RECOMMENDATIONS

AMSAA makes the following recommendations regarding STNDMob Fidelity 1 and 2.

a. In order to maintain version control and to assure that all Users are using the proper data set, recommend that the Fidelity 1 and 2 speed tables and the vehicleTypeIDMap.xml file include a version control number(s). The speed tables and the vehicleTypeIDMap.xml file are stored at the Joint Data Center, AMSAA, where they are distributed to the User community. Undoubtedly, these data will be modified from time to time, and to assure the most up-to-date data are being delivered to the User the files should be uniquely identified.

There is a similar situation with the STNDMob Fidelity 3 and 4 vehicle files; however, the files have a unique creation date included. While this identification is very useful, a version number may be more easily tracked and maintained. This topic is discussed in Section 3.2.

b. STNDMob Fidelities 1 and 2 are considered low resolution tools while Fidelities 3 and 4 are medium resolution tools. Recommend that the STNDMob documentation explicitly distinguish between the types of studies that should use the low resolution tools and those that should use the medium resolution tools. This report discusses these distinctions in Section 2.1, but these details should also be included within all User documentation.

c. With respect to Fidelity 1 fording and swimming predictions, recommend selecting the specific vehicle's fording and swimming speed from the VehicleTypeIDMap.xml file, as is the case for Fidelity 2, to assure proper fording and swimming characteristics are selected. If the User is interested in a vehicle's fording and swimming characteristics, the simplest work around would be for the User to use Fidelity 2 predictions and avoid Fidelity 1. This topic is discussed in Section 3.7. The User at least should have a good understanding of the prediction process regarding fording and swimming estimates.

d. Recommend that the two amphibious vehicle bins be deleted and that these vehicles be depicted by their appropriate representative platform. STNDMob uses two separate bins for amphibious vehicles. This creates a situation where an amphibious vehicle that has different mobility characteristics from the M113A2 (i.e., the tracked amphibious representative vehicle) or the LAV25 (i.e., the wheeled amphibious representative vehicle) is misrepresented simply due to its amphibious nature. The impact of this is not quantifiable since it is situation dependent. For the case of a hypothetical high mobility tracked vehicle that is also amphibious, the error in speed prediction could average 10 mph based on a comparison of the amphibious bin for tracked vehicles and the M1A1 (i.e., high mobility tracked representative vehicle). In the case of a fording or swimming situation, the work around described in recommendation "c." above could possibly be applied. This topic is discussed further in Section 3.6.

e. A review of Section 3.4 (i.e., "For Fidelity 1 and 2, how do NRMM and the STNDMob speed predictions compare for non-representative vehicles?") and Appendix A revealed that Fidelity 2 predictions may not always provide more accurate predictions relative to Fidelity 1. The Bin 1 comparison in Section 3.4 shows that five of the six scenarios tested had better accuracy with Fidelity 2. Subsequent examinations in Appendix A, albeit on fewer terrains per bin, indicate that only Bins 2 and 4, of the remaining ten bins, have Fidelity 2 predictions that are more accurate than Fidelity 1. The difference between the bins is not large, with the average difference between Fidelity 1 and 2 never varying by more than 1.93 mph.

Due to this mix of findings, it is recommended, for any vehicle of significant interest, that a study be performed to develop the most appropriate bin factor. In most cases, it appeared that by developing and using a customized bin factor, based on a comparison of Fidelity 1 and 2 results as was done in this report, that Fidelity 2 results are generally more accurate. An alternate solution is to develop a new bin factor methodology. This alternative, however, would likely require a significant study effort.

5. CONCLUSIONS

This technical report is a validation of STNDMob Fidelities 1 and 2. STNDMob Fidelities 3 and 4 have not been validated at the time of this writing. This report does <u>not</u> address model accreditation. The User accredits whether the tool is appropriate for any particular study. The User should look towards this validation, at least in part, to determine whether the STNDMob Fidelity 1 and 2 is appropriate for their application.

STNDMob Fidelities 1 and 2 are a robust set of tools if used within its design window. This window is quantified within this report's main body and supporting appendices. Section 2.1 describes the intended use of these tools and is critical to the proper use of the STNDMob. Section 3.8 identifies some known limitations, and Section 4 are AMSAA's recommendations to the STNDMob developers. These three sections, in particular, should be considered by the User prior to the start of any accreditation process.

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REFERENCES

1. Baylot, A., Burhman, G., Green, J., Richmond, P., Goerger, N., Mason, G., Cummins, C., and Bunch, L. (2005, February). Standard for Ground Vehicle Mobility, ERDC GSL Technical Report TR-05-6

2. Bullock, D., (1994, September). Methodology for the Development of Inference Algorithms for Worldwide Application of Interim Terrain Data to the NATO Reference Mobility Model, ERDC GSL Technical Report GL-94-37

3. Baylot, A. and Gates, B., (2002, November). Procedure for Categorizing Ground Vehicles, ERDC GSL Technical Report TR-02-21

4. Trewartha, G.T., Goode's World Atlas, 16th edition, Rand McNally and Company, 1983.

5. http://www.msrr.army.mil/astars/doclib.cfm?AMSO_RID_1000042; July 8 2004. Army Standards Repository System (1999, April). Standard for Ground Vehicle Movement.

6. http://geography.about.com/library/weekly/aa011700a.htm?terms=Koppen+Climate+Map; 12 August 2004.

7. http://geography.about.com/library/weekly/aa011700b.htm; 12 August 2004.

8. http://www.wordiq.com/definition/K%F6ppen_climate_classification#Trewartha_climate_classification_scheme; 11 August 2004.

9. Alhvin, R. and Haley, P., (1992, December). NATO Reference Mobility Model Edition II, NRMM II Users Guide, ERDC GSL Technical Report GL-92-19.

10. Alhvin, R., (2003, June). NATO Reference Mobility Model Edition II, NRMM II User's Guide Addendum Model Changes and Updates through Version 2.6.9., ERDC GSL Miscellaneous Paper.

11. Horrigan, T. and Bates, R. E., (1995, September). Estimated Snow Parameters for Vehicle Mobility Modeling in Korea, Germany and Interior Alaska, ERDC Cold Regions Research & Engineering Laboratory (CRREL) Special Report 95-23.

12. Baylot, A. <Alex.Baylot@us.army.mil> (2006, May 18). ERDC GSL. RE: STNDMob Terrain Definitions. [Personal email]. (2006, May 18}.

    Jones, R. <Randolph.A.Jones@erdc.usace.army.mil> (2006, May 19). ERDC GSL. FW: TerrainDefinitions.pdf [Personal email]. (2006, May 19).

13. http://chinook.phsx.ukans.edu/atmo105/ovrhd_12_4_03.ppt; 12 August 2004.

APPENDIX A – FIDELITY 1, 2, AND NRMM SPEED PREDICTION COMPARISON

APPENDIX A - FIDELITY 1, 2, AND NRMM SPEED PREDICTION COMPARISON

This appendix addresses the following question: For Fidelity 1 and 2, how do NRMM and the STNDMob speed predictions compare for non-representative vehicles? This investigation is a continuation of Section 3.4 of the main report. Please reference Section 3.4 for a detailed description of the methodology used to make the comparisons. Section 3.4 compared the NRMM, Fidelity 1 and Fidelity 2 speed predictions for a Bin 1 non-representative vehicle (i.e., M2A2). Bin 12, unmanned ATV, is not examined since there is not a suitable comparison vehicle file. This appendix examines a non-representative vehicle from each of the remaining ten STNDMob bins. The tests exercised in Section 3.4 used the following environmental conditions:

- Cross-Country – Dry
- Cross-Country – Wet
- Cross-Country / Trail – Snow
- Road / Trail – Dry
- Road / Trail - Wet
- Road – Snow

This appendix will examine one of these conditions per bin. Climate zone 13 (i.e., Undifferentiated Highlands) was used exclusively in Section 3.4. This appendix will sample the other three climate zones. Table 16 is a quick reference for the bin descriptions and their representative vehicles.

Table 16. STNDMob Fidelity 1 and 2 Bins with Associated Representative Vehicles.

Bin No.	Representative Vehicle	Description	Non-Representative Vehicle Used
1	M1A1	High Mobility Tracked	M2A2
2	M270 MLRS	Medium Mobility Tracked	M270 MLRS
3	M60 AVLB	Low Mobility Tracked	M88A1
4	M1084 MTV	High Mobility Wheeled	M1025A2/HMMWV
5	M985 HEMTT	Medium Mobility Wheeled	Zil-135
6	M917 Dump Truck	Low Mobility Wheeled	M1074/PLS
7	M1084/M1095	High Mobility Wheeled w/Towed Trailer	M923/M200A1
8	M985/M989	Medium Mobility Wheeled w/Towed Trailer	M915A2/M872
9	M911/M747 HET	Low Mobility Wheeled w/Towed Trailer	M1070/M1000
10	M113A2	Tracked Amphibious Combat Vehicle	M-1974 2S1
11	LAV25	Wheeled Amphibious Combat Vehicle	Stryker-ICV
12	Unmanned All Terrain Vehicle (ATV)	Unmanned Kawasaki Light ATV	None

1.0 Bin 2 – Medium Mobility Tracked.

Figure 28. T-72.

The Bin 2 non-representative vehicle used for this test is the Russian T-72 main battle tank, Figure 28. The bin factor for the T-72 is .94. The representative vehicle for Bin 2 is the US Army's M270 MLRS, Figure 29. All STNDMob speed table predictions for Bin 2 therefore originated from NRMM predictions of the MLRS. In order to use these MLRS predictions to represent the T-72's speed, the T-72's bin factor (.94) is applied to the MLRS predictions when using Fidelity 2. The bin factor is not applied when using Fidelity 1. As described in Section 2.1.2, the bin factor is simply the ratio of the non-representative vehicles top speed to the representative vehicles top speed. All tests were performed using Climate Zone 4, Dry Climates, with no interpolation. The scenario was set at Cross-Country – Dry.

Figure 29. M270 MLRS.

A key element examined was the difference between the T-72 STNDMob Fidelity 1 and 2 predictions and the NRMM predictions. This difference is simply referred to as the "prediction delta". With Fidelity 2 implemented, the tendency was for the mean and standard deviation to decrease slightly relative to the Fidelity 1 statistics as shown in Table 17.

Table 17. T-72 {Climate Zone 4, Cross-Country, Dry}.

Fidelity 1		Fidelity 2	
	Dry		Dry
Mean	1.32	Mean	0.98
Standard Deviation	3.67	Standard Deviation	3.54
Range	34.88	Range	35.06
Minimum	-15.49	Minimum	-16.83
Maximum	19.39	Maximum	18.23
Count	26928	Count	26928

All units are mph except for "Count"

Fidelity 2 predictions are not always more accurate relative to Fidelity 1 predictions. The bin factor is applied equally to both over and under STNDMob predictions. When the bin factor is less than 1.0 and the STNDMob over-predicts relative to NRMM predictions, the application of the bin factor moves the estimate closer to the NRMM baseline prediction. If the STNDMob under-predicts and the bin factor is less than 1.0, then the application of the bin factor moves the estimate further from the NRMM baseline prediction. If the bin factor is greater than 1.0, then the opposite is true.

This phenomenon is readily seen in Figure 30. In the upper right portion of the chart, the STNDMob is over-predicting (i.e., STNDMob is predicting a faster speed than NRMM; thus the STNDMob prediction minus the NRMM prediction yields a positive value). When the 0.94 bin factor is applied in this situation the resulting Fidelity 2 curve is moved closer to the NRMM baseline (i.e., where STNDMob – NRMM = 0 mph). In the lower left portion of the chart, the STNDMob is under-predicting, so when the bin factor is applied the resulting Fidelity 2 curve is moved further away from the NRMM baseline making the Fidelity 2 prediction slightly less accurate than the Fidelity 1 prediction.

The prediction delta types are defined as follows:

Over: STNDMob Prediction – NRMM Prediction = Positive Value
Even: STNDMob Prediction – NRMM Prediction = 0 [i.e., STNDMob and NRMM prediction are the same]
Under: STNDMob Prediction – NRMM Prediction = Negative Value

Figure 30 can be used to identify whether the prediction delta is over, under, or even. The reader should note that the each prediction delta point may mask multiple points stacked one upon another.

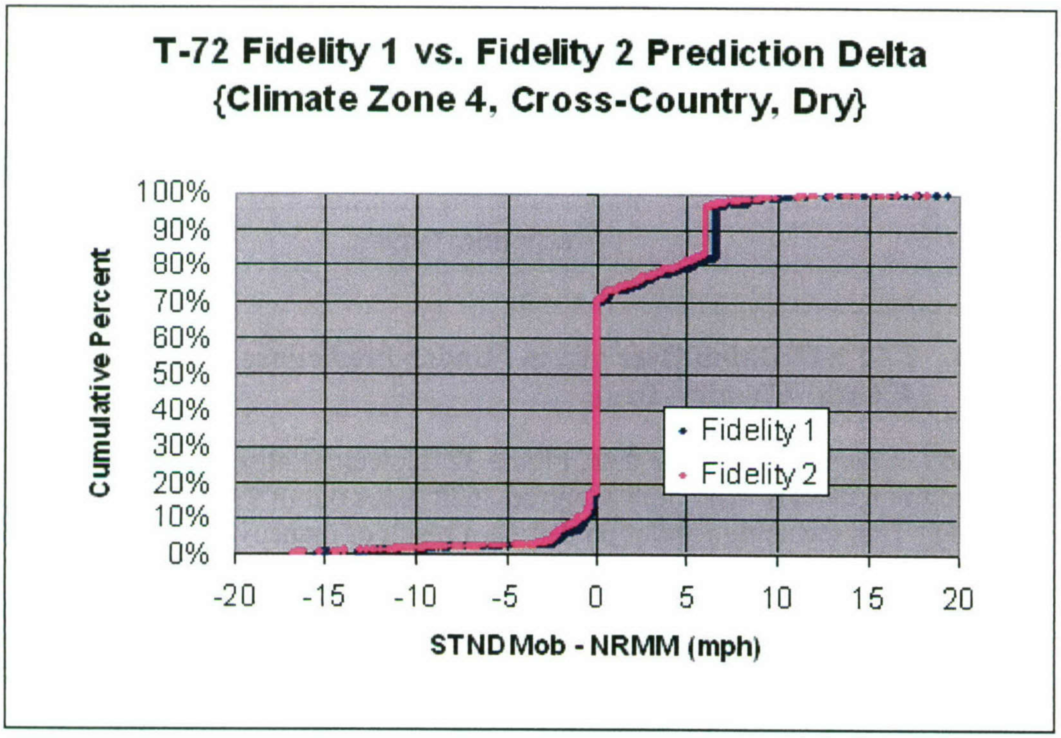


Figure 30. T-72 Fidelity 1 vs. Fidelity 2 Prediction Delta {Climate Zone 4, Cross-Country, Dry}.

Figure 31 alleviates the stacking issue and identifies the exact number of over, under, and even-predictions. In the case of the T-72, there are more over-predictions that under-predictions. Due to the bin factor, Fidelity 2 has 6.0 percent more under-predictions than Fidelity 1. While Fidelity 2 produced more under-predictions, it also produced fewer over-predictions. Over-prediction speed deltas are generally larger relative to under-prediction speed deltas, thus the overall effect of applying the Fidelity 2 bin factor (.94) delivers better prediction accuracy relative to Fidelity 1. The overall effect can be seen in the mean and standard deviation changes identified in Table 17.

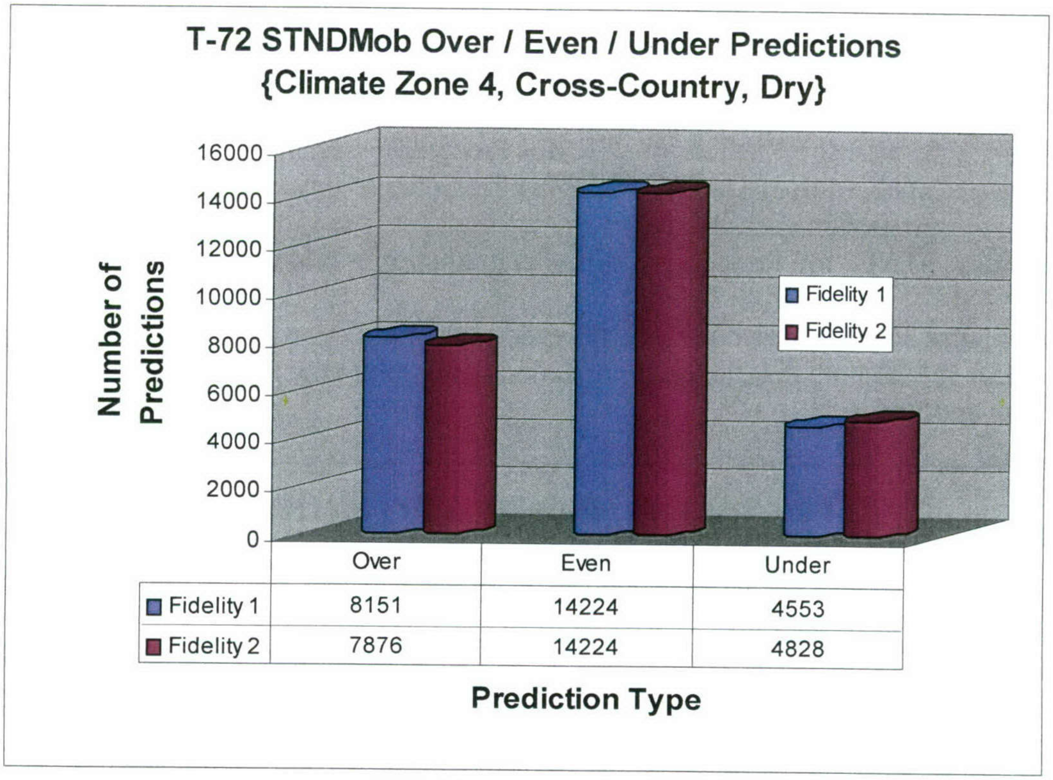


Figure 31. T-72 STNDMob Over / Even / Under-Predictions {Climate Zone 4, Cross-Country, Dry}.

For another perspective of the data, Figure 32 depicts the absolute value of the T-72 mph. The prediction delta of 6.66 mph occurred 3528 times out of the sample population of 26,928 (13.1%). This recurring prediction delta is a result of maneuvering speed limitations associated with the MLRS (T-72's representative vehicle) and the T-72 when obstacle spacing is at 30ft. Given this spacing and appropriate vegetation and slope characteristics, the T-72 NRMM prediction is 11.1 mph while the T-72 STNDMob prediction (based on the representative vehicle) is 4.4 mph; thus producing a prediction delta of 6.7 mph.

As described in Table 17, the range of STNDMob predictions can be at times fairly large (e.g., +19.4 mph for Fidelity 1 and +18.2 mph for Fidelity 2). Errors of this magnitude, however, are the exception rather than the rule. Figure 32 also gives a clearer understanding of the situation. For Fidelity 1, 76.9 percent of the predictions are within ±5 mph (95% within ±7.64 mph). For Fidelity 2, the number of predictions within ±5 mph rises to 78.7 percent (95% within ±6.56 mph). The terrain (Climate Zone 4, Dry) produced approximately 52.8 percent NOGO situations (speed-made-good = 0 mph) with STNDMob using the representative vehicle (i.e., MLRS). The T-72's NRMM results indicated an increased number of NOGO situations to 55.2 percent. The high number of NOGO occurrences was attributed to large vehicles attempting to traverse terrain with closely spaced, impassable, obstacles. Therefore, for the terrain units not resulting in a NOGO situation (i.e., a speed could be achieved), slightly fewer than 50 percent had prediction deltas outside ±5 mph.

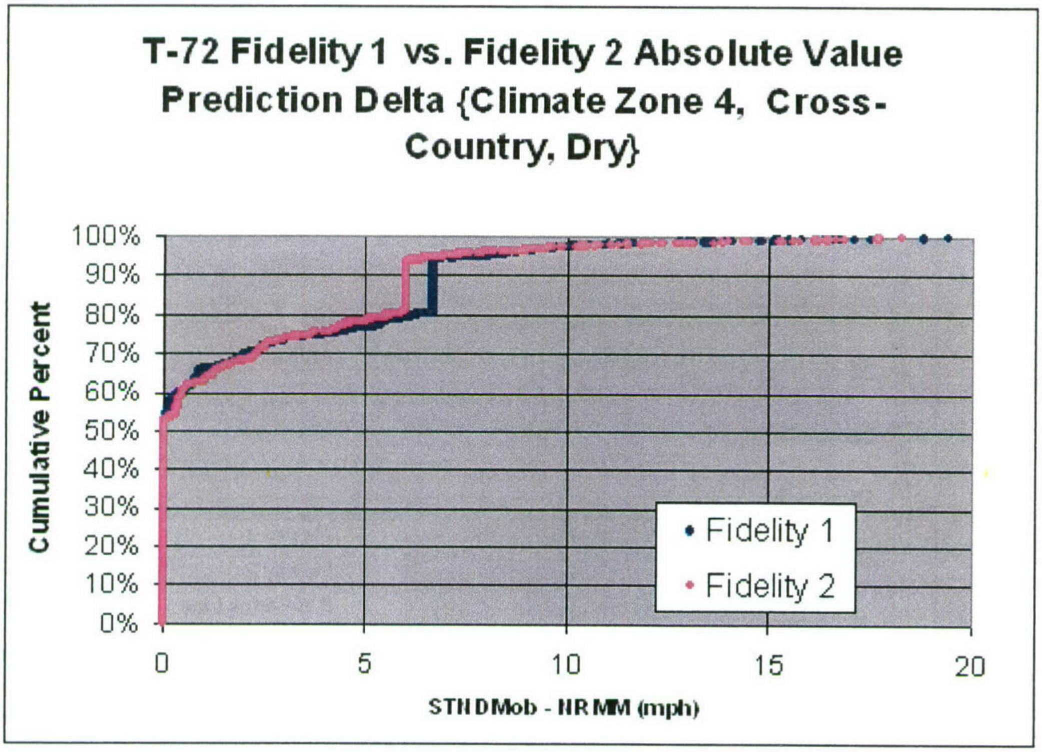


Figure 32. T-72 Fidelity 1 vs. Fidelity 2 Absolute Value Prediction Delta {Climate Zone 4, Cross-Country, Dry}.

Figure 33 is a scatter plot depicting the T-72's STNDMob speed predictions versus NRMM speed predictions. As expected, the Fidelity 2 cases are located directly below their associated Fidelity 1 case due to the application of the bin factor. If the bin factor were greater than 1.0, then the Fidelity 2 cases would have been directly above their Fidelity 1 counterparts. The scatter plot provides an excellent graphic regarding how well the STNDMob is predicting. If the STNDMob predicted perfectly (i.e., exactly the same as the NRMM), then all of the data points would fall on the yellow reference line. One interesting item of note is the horizontal data spikes that can be seen at 18.8, 22.3, and 28.0 mph (Fidelity 1 values indicated). At these points, many of the maximum prediction deltas are occurring between the STNDMob and NRMM predictions.

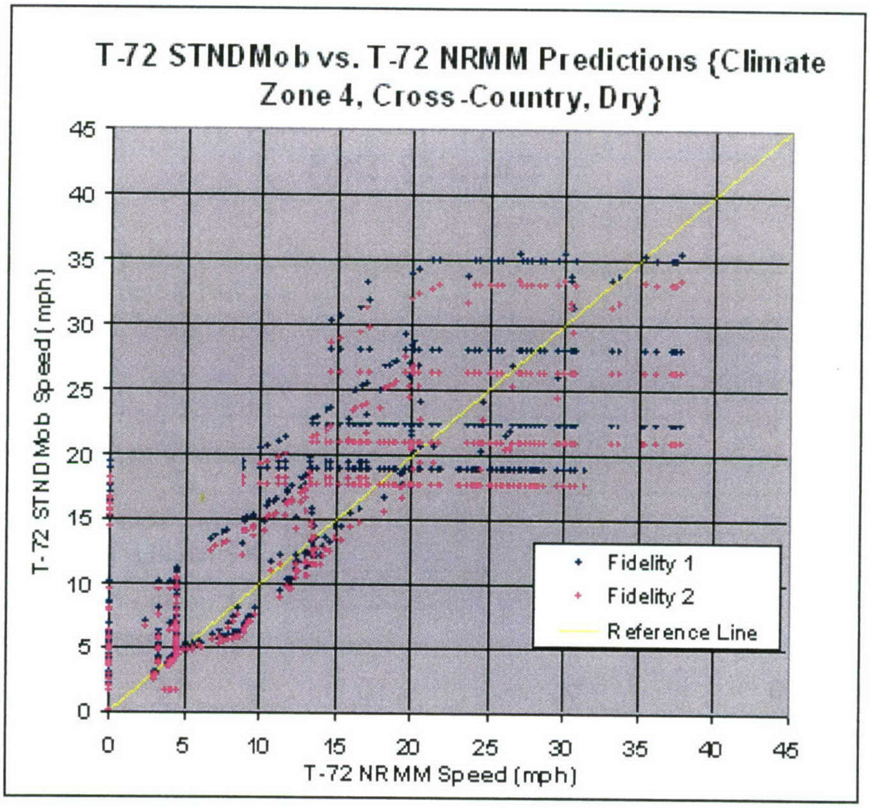


Figure 33. T-72 STNDMob vs. T-72 NRMM Predictions. {Climate Zone 13, Cross-Country, Dry}.

Within an NRMM vehicle file, there are speed limiting factors that are used to bound a vehicle's speed given certain environmental conditions. One of these limiting factors is the maximum driver absorbed energy given the vehicle's speed and the root-mean-square (rms) of the surface roughness. The maximum absorbed power for a driver over an eight hour period is traditionally given at six watts. To keep below the six watt maximum value, in rougher terrain, the speed is set at a lower acceptable limit. The T-72 and MLRS's roughness versus speed relationships for six watts maximum absorbed power is shown in Table 18 and Table 19, respectively.

When Table 18 and Table 19 are compared, it is clear that on smoother terrain the T-72 can be driven at greater speeds before being limited by driver absorbed power. When T-72 speeds are predicted using NRMM, the ride limiting speeds are taken from Table 18. When T-72 speeds are predicted using STNDMob, the ride limiting speed is taken from Table 19, and the Table 19 ride limiting speeds are slower on the smoother surfaces relative to Table 18. Table 19 is used because the representative vehicle for the T-72 is the Bin 2 representative vehicle (i.e., MLRS). The Bin 2 representative vehicle is capping the speed, thus the horizontal data groupings.

Upon examination of the surface conditions during these periods, the roughness conditions are 1.8, 1.4, and 1.0 rms. Interpolating within Table 19 for the given surface roughness values, the horizontal grouping values of 18.8, 22.3, and 28.0 mph speed limits can be obtained relative to the surface roughness conditions. Here you have a situation where the representative vehicle (i.e., MLRS) is less capable with respect to vehicle ride (i.e. slower speeds at lower surface roughness values) compared to the non-representative vehicle (i.e., T-72). This is the opposite situation of the Bin 1 case examined in Section 3.4 (Cross-Country/Dry) where the representative vehicle was the more capable, and thus produced predominant vertical groupings, see Figure 8. Figure 8 and Figure 33 clearly identify the impact of the vehicle ride speed limitations upon the predictions.

One will also note a horizontal grouping at approximately 35.1 mph (Fidelity 1 value indicated). This also looks to be a speed limitation caused by vehicle ride similar to the other noted occurrences. Upon closer inspection of the data, however, the MLRS is not being limited by ride at this speed, but by "soil, slope, and vegetation resistances". This is an instance were multiple speed limiting factors are having an impact (i.e., causing horizontal groupings) upon the predictions.

Table 18. T-72 Vehicle Ride Characteristics (6 watts max).

Surface Roughness (rms)	0	1.6	2	2.5	3	4	5
Speed Limit (mph)	38	38	25	15	12	8	7

Table 19. MLRS Vehicle Ride Characteristics (6 watt max).

Surface Roughness (rms)	0	.9	1	1.2	1.5	1.7	2	2.5	3	4	5
Speed Limit (mph)	36	36	28	24.5	21.2	19.5	17.5	15	12.7	10	8.5

2.0 Bin 3 – Low Mobility Tracked.

The Bin 3 non-representative vehicle used for this test is the US Army's M88A1 recovery vehicle, Figure 34. The bin factor for the M88A1 is 0.88. The representative vehicle for Bin 3 is the US Army's M60A1 Armored Vehicle Launched Bridge (M60A1 AVLB), Figure 35. All STNDMob speed table predictions for Bin 3 therefore originated from NRMM predictions of the AVLB. In order to use these AVLB predictions to represent the M88's speed, the M88's bin factor (0.88) is applied to the AVLB predictions when using Fidelity 2. The bin factor is not applied when using Fidelity 1. All tests were performed using Climate Zone 6, Humid Mesothermal Climates (i.e., Sub-Tropical Regions), with no interpolation. The scenario was set at Cross-Country – Wet.

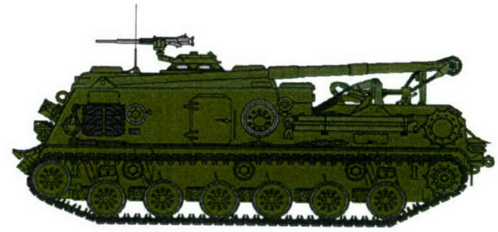


Figure 34. M88A1.

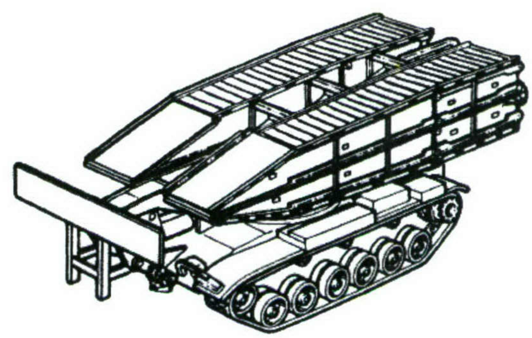


Figure 35. M60A1 AVLB.

The prediction delta statistics for the M88A1 can be found in Table 20. With Fidelity 2 implemented, the tendency was for the mean and standard deviation to increase slightly relative to the Fidelity 1 statistics. This particular dataset however depicts an interesting situation where the maximum range of the Fidelity 2 dataset did not exceed zero (i.e., no over-predictions).

Table 20 – M88A1 {Climate Zone 6, Cross-Country, Wet}.

Fidelity 1		Fidelity 2	
	Wet		Wet
Mean	-3.16	Mean	-3.44
Standard Deviation	2.16	Standard Deviation	2.25
Range	14.29	Range	12.12
Minimum	-11.44	Minimum	-12.12
Maximum	2.85	Maximum	0.00
Count	26928	Count	26928

All units are mph except for "Count"

Figure 36 and Figure 37 provide a clear picture regarding over, under, and even-predictions. Figure 36 indicates that only a very small number of over-predictions have taken place and all of those are associated with Fidelty 1. When the bin factor (0.88) is applied to the Fidelity 1 predictions, the speeds are reduced to the point where the Prediction Delta (STNDMob prediction – NRMM prediction) never exceeds zero.

An investigation was performed to determine the feasibility of the AVLB never exceeding the speed attained by the M88A1. It was revealed that the AVLB simply weighs more (11,000 lbs) and has the same, or lower, tractive force as the M88A1. In addition, the AVLB has reduced visibility relative to the M88A1. These factors dictate that when soil resistance or visibility are the speed limiting factors, the M88A1 will attain the higher speed. A review of the NRMM results confirms that almost all speeds were limited by either visibility or soil and slope resistances. Therefore it is logical that the M88A1 will almost always exceed the speeds attained by the AVLB.

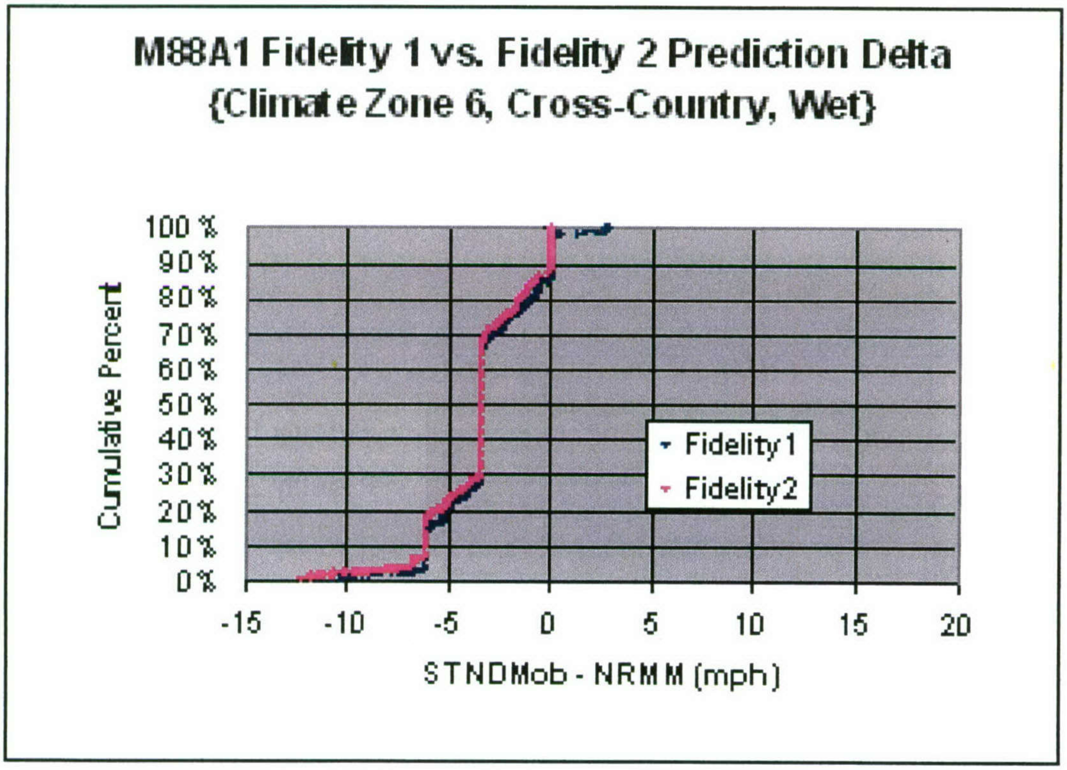


Figure 36. M88A1 Fidelity 1 vs. Fidelity 2 Prediction Delta {Climate Zone 6, Cross-Country, Wet}.

Figure 37 shows the absolute value comaprison of the prediction deltas. Because very few prediction deltas are positive, Figure 37 is simply a rotated version of Figure 36. What Figure 37 does show is that, for Fidelity 1, 80.0 percent of the prediction deltas are within ± 5 mph and that 77.4 percent of all Fidelity 2 prediction deltas are within ± 5 mph. At ± 6.05 mph the prediction accuracy increases to 95 percent for Fidelity 1. Within ±6.74 mph, the prediction accuracy increases to 95 percent for Fidelity 2.

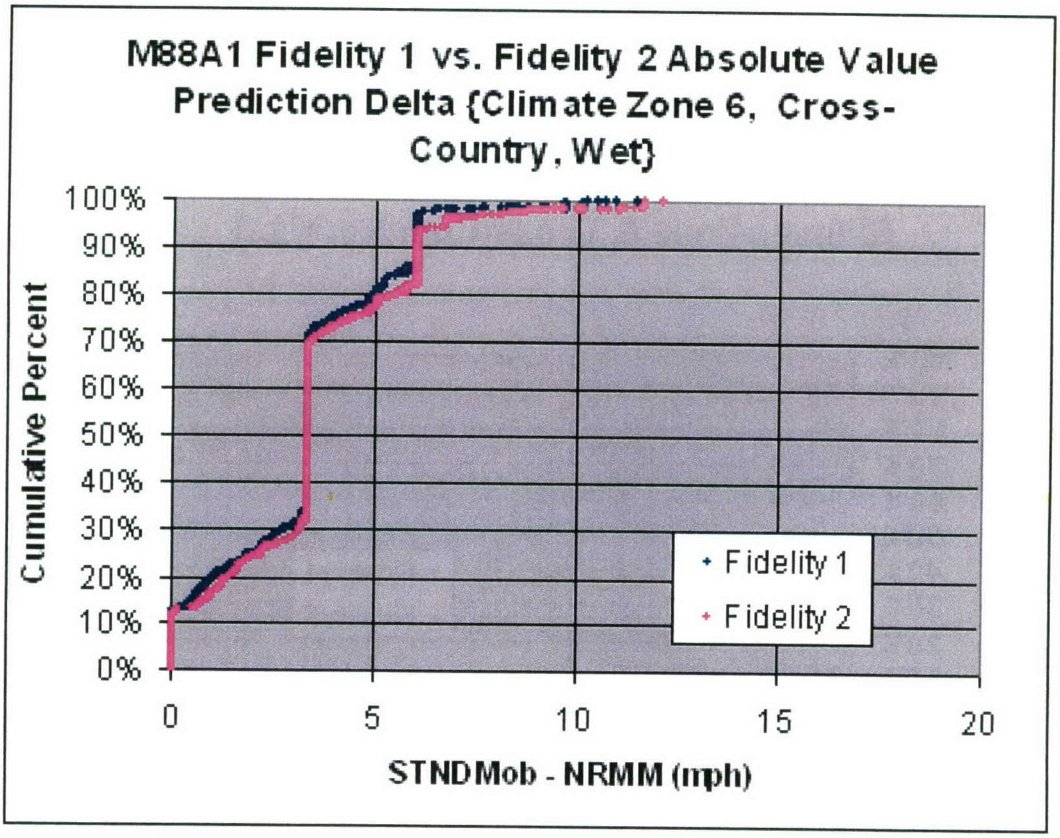


Figure 37. M88A1 Fidelity 1 vs. Fidelity 2 Absolute Value Prediction Delta {Climate Zone 6, Cross-Country, Wet}.

Figure 38 is a scatter plot depicting the M88A1's STNDMob speed predictions versus NRMM speed predictions. As expected, the Fidelity 2 cases are located directly below their associated Fidelity 1 cases due to the application of the bin factor. One interesting item of note is the horizontal and vertical data spikes. As was discussed previously, the horizontal lines can indicate terrain units where vehicle ride has limited the speed. In this case, the horizontal lines that occur at approximately16.3 mph (Fidelity 1) and 14.4 mph (Fidelity 2) are an indication that the M60A1 AVLB speed was limited by vehicle ride. An examination of the terrain data and vehicle file confirmed that vehicle ride was the limiting factor.

The second set of horizontal lines, occurring at 7.3 mph (Fidelity 1) and 6.4 mph (Fidelity 2) are <u>not</u> due to vehicle ride. An examination of these data indicates that these lines are due to a tractive force limitation. There are enough of these terrain data points to create a line due to recurring soil conditions. The vertical line, coming at the maximum of the speed range, indicates that the speed was limited by the vehicle's generated tractive force. The M88A1 is only able to attain an approximate speed of 27 mph on any given terrain due to its available tractive force. The representative vehicle, AVLB, achieves a range of speeds over these same terrain units creating what appears to be a data spike.

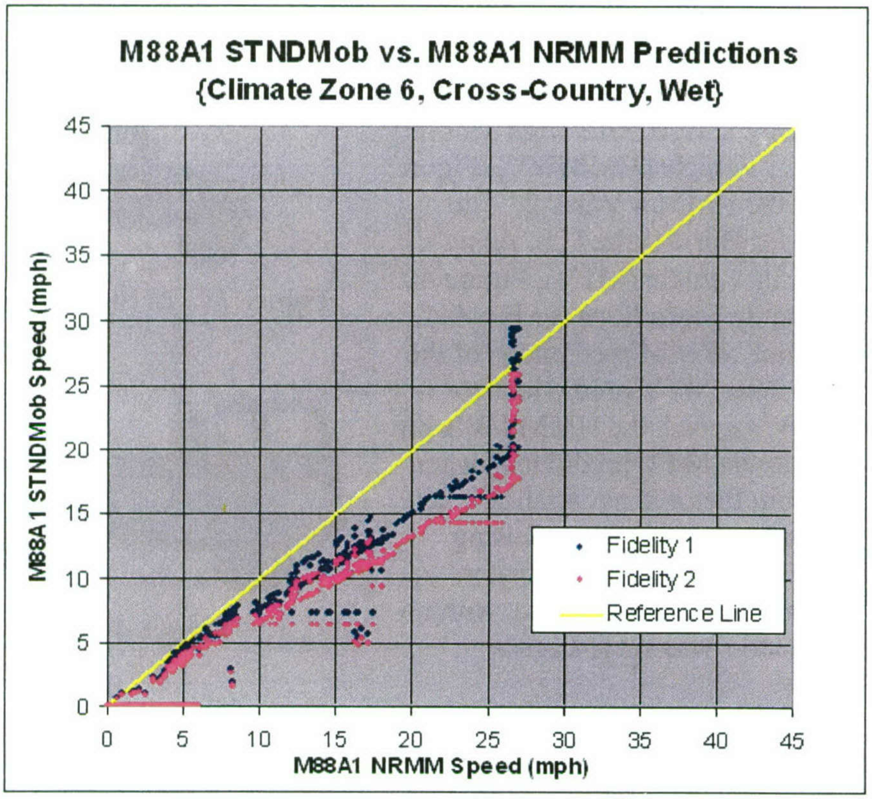


Figure 38. M88A1 Fidelity 1 vs. Fidelity 2 Predictions {Climate Zone 6, Cross-Country, Wet}.

3.0 Bin 4 – High Mobility Wheeled.

The Bin 4 non-representative vehicle used for this test is the U.S. Army's M1025A2 High Mobility Multi-Purpose Wheeled Vehicle (HMMWV), Figure 39. The bin factor for the HMMWV is 1.2. The representative vehicle for Bin 4 is the U.S. Army's M1084 Medium Tactical Vehicle (MTV), Figure 40. All STNDMob speed table predictions for Bin 4 therefore originated from NRMM predictions of the MTV. In order to use these MTV predictions to represent the HMMWV's speed, the HMMWV's bin factor (1.2) is applied to the MTV predictions when using Fidelity 2. The bin factor is not applied when using Fidelity 1. All tests were performed using Climate Zone 8, Humid Microthermal Climates (e.g., Continental, Warm Summer Regions), with no interpolation. The scenario was set at Cross-Country / Trail – Snow.

Figure 39. M1025A2/HMMWV.

Figure 40. M1084/MTV.

Table 21. HMMWV {Climate Zone 8, Cross-Country / Trail, Snow}.

Fidelity 1		Fidelity 2	
	Snow		Snow
Mean	-1.38	Mean	-0.08
Standard Deviation	4.58	Standard Deviation	5.29
Range	44.34	Range	46.66
Minimum	-32.35	Minimum	-29.95
Maximum	11.99	Maximum	16.71
Count	27684	Count	27684

All units are mph except for "Count"

The prediction delta statistics for the HMMWV can be found in Table 21. With Fidelity 2 implemented, the tendency was for the mean to approach zero while the standard deviation increased relative to the Fidelity 1 statistics. It should also be noted that the minimum-to-maximum value's range is rather broad. The following paragraphs will discuss this in more detail.

Figure 41 and Figure 42 provide a clearer picture regarding over, under, and even-predictions as well as graphically displaying the broad range of prediction deltas noted earlier. This broad range initially implies that the MTV may not be very representative of the HMMWV. As discussed in previous analyses, this is not necessarily true. Referring to Figure 42 it can be seen that 63.4 percent of Fidelity 1 prediction deltas, and 82.1 percent of Fidelity 2 prediction deltas are within 5 mph. Because several data points exceeded the 5 mph prediction delta by only a small margin, an additional check was performed at 6 mph. In that case, 85.0 percent of Fidelity 1 data points and 84.1 percent of Fidelity 2 data points have a prediction delta less than 6 mph. In addition, 95 percent of the prediction deltas are within ±8.01 mph for Fidelity 1 and ±10.05 mph or less for Fidelity 2.

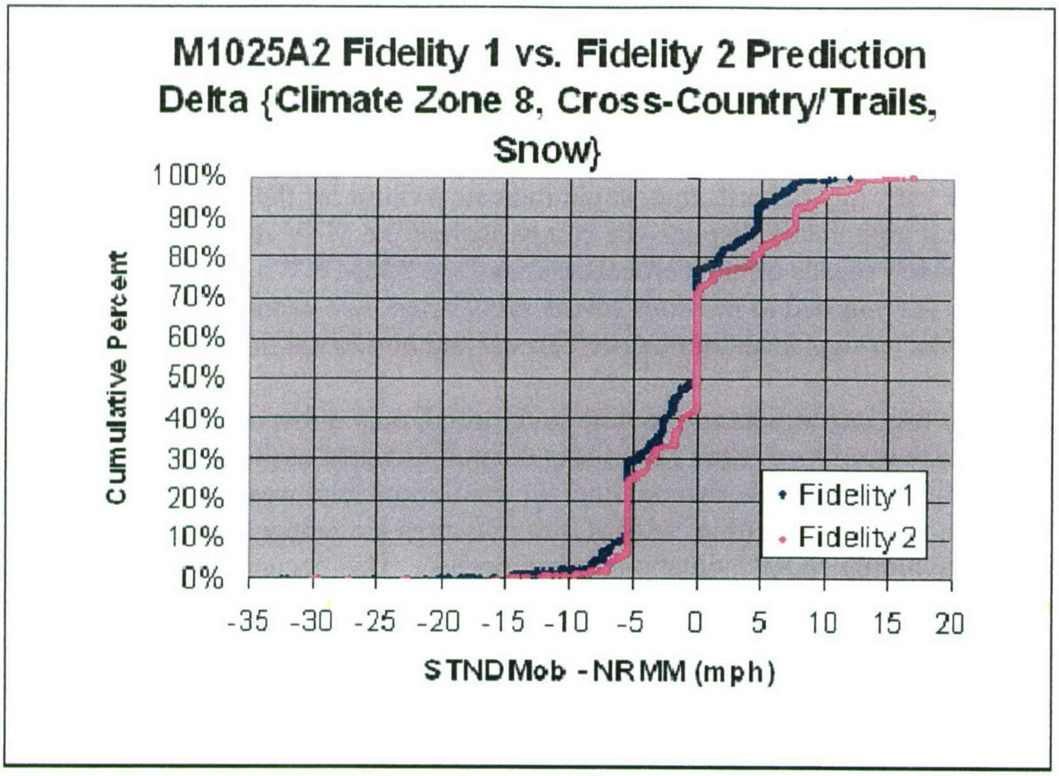


Figure 41. M1025A2 Fidelity 1 vs. Fidelity 2 Prediction Delta {Climate Zone 8, Cross-Country / Trail, Snow}.

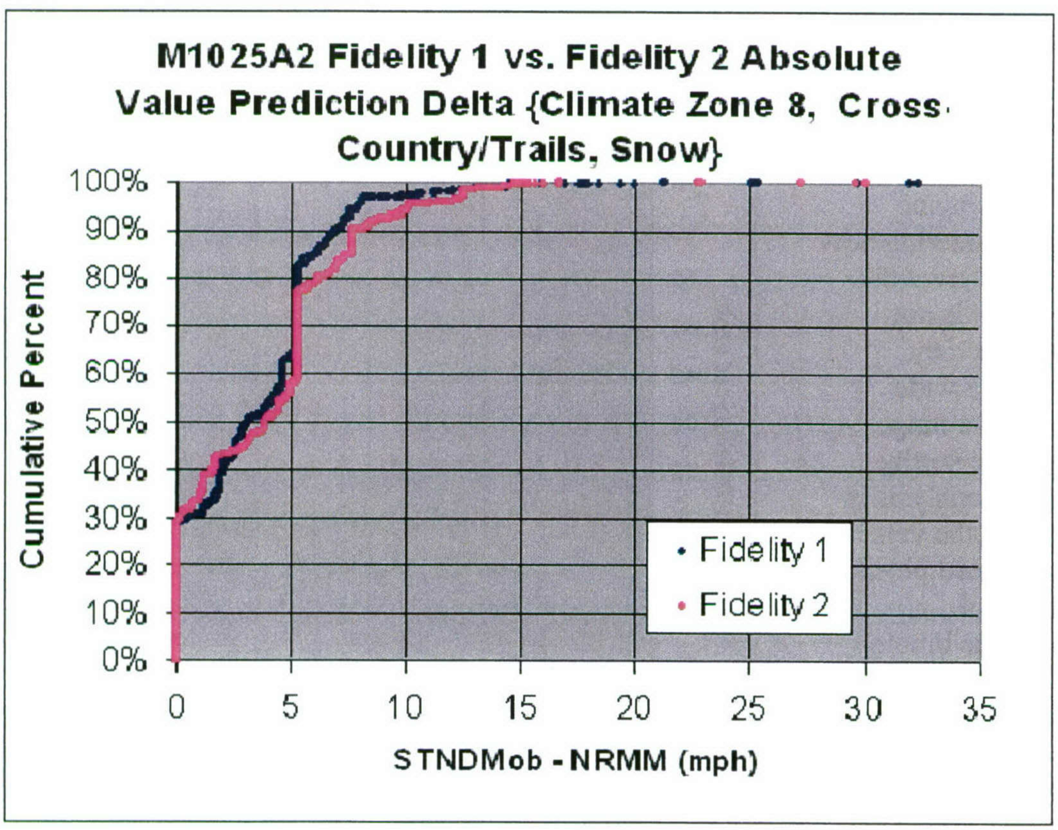


Figure 42. M1025A2 Fidelity 1 vs. Fidelity 2 Absolute Value Prediction Delta {Climate Zone 8, Cross-Country / Trail, Snow}.

To determine why these two vehicles produced such a large prediction delta range, a comparison of the vehicles' performance was conducted. First, Figure 43 was examined to determine if there were any patterns that would indicate a cause for the large range. Figure 43 was used because it graphically displays the comparison of the MTV results (shown as the HMMWV STNDMob speeds on the vertical axis) and the HMMWV's NRMM results (horizontal axis). As opposed to previous scatter plots where two or three trends were readily visible, Figure 43 has a significant number of vertical and horizontal lines indicating trends.

Because it was impractical to examine every trend, only a few of the trends that produced wide variations were examined. One example is the point located at (44.34, 14.39). In this case, and for all the points along that horizontal line, the prediction delta was produced because of a tire speed limit on the MTV. Within NRMM, tire pressures are reduced on a vehicle to increase traction, thereby avoiding NOGO situations, when needed. This occurs frequently on soft soils. On the particular terrain unit under investigation, NRMM was able to avoid a NOGO situation by lowering the tire pressures on the MTV. For the tire pressure used on this terrain unit, a maximum speed of 12 mph is assigned. This speed is vehicle dependent and is intended to prevent the tire from deteriorating at high speeds when under-inflated. The 12 mph for the MTV is multiplied by the bin factor of the HMMWV (1.2) to achieve the 14.39 mph speed shown in the graph. Because the HMMWV is actually capable of attaining a 44.34 mph speed, the prediction delta is large. Another example of a large speed delta is the point (45.25, 25.9). In this case, both vehicles are limited by the soil, slope, and vegetation resistances with the MTV being more restricted.

Both examples seem to indicate that basic vehicle differences dictate these variances (e.g., weight, tires, engine power). Considering how physically different the vehicles are, it is not surprising that they produce such a wide prediction delta range. The more noteworthy aspect of this analysis is that, although the vehicles have pronounced physical and operational differences, the binning methodology appears to have worked sufficiently to keep over 80 percent of the prediction deltas under 6 mph.

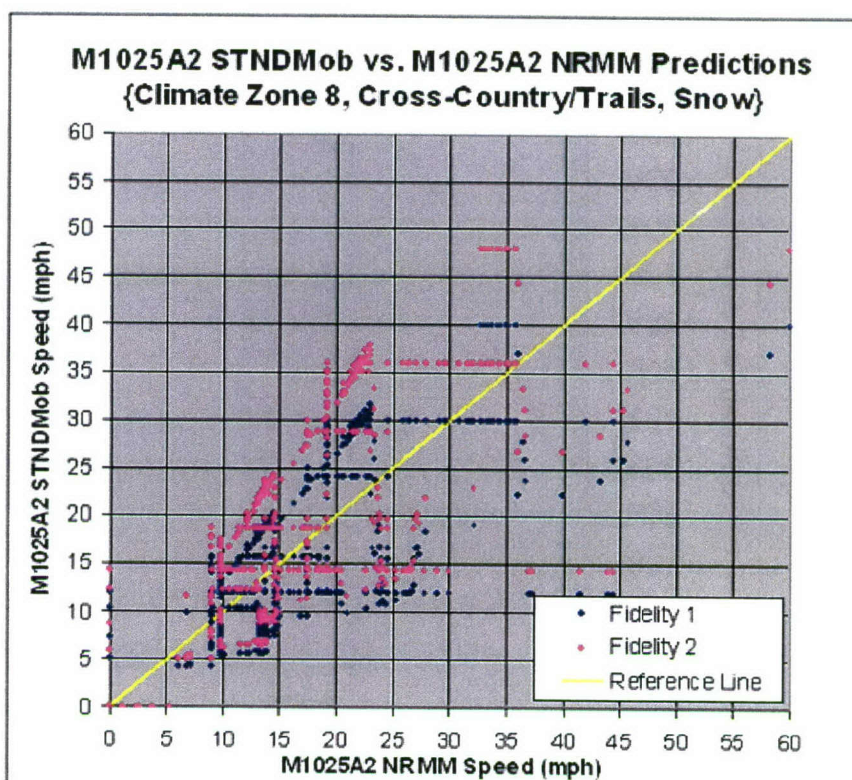


Figure 43. M1025A2 Fidelity 1 vs. Fidelity 2 Predictions {Climate Zone 8, Cross-Country / Trail, Snow}.

4.0 Bin 5 – Medium Mobility Wheeled.

The Bin 5 non-representative vehicle used for this test is the Russian Zil-135 8x8 truck, Figure 44. The bin factor for the Zil-135 is 0.74. The representative vehicle for Bin 5 is the US Army's M985 Heavy Expanded Mobility Tactical Truck (HEMTT), Figure 45. All STNDMob speed table predictions for Bin 5 therefore originated from NRMM predictions of the HEMTT. In order to use these HEMTT predictions to represent the Zil-135's speed, the Zil-135's bin factor (0.74) is applied to the HEMTT predictions when using Fidelity 2. The bin factor is not applied when using Fidelity 1. All tests were performed using Climate Zone 6, Humid Mesothermal Climates (e.g., Humid Subtropical), with no interpolation. The scenario was set at Cross-Country – Dry.

Figure 44. Zil-135.

Figure 45. M985/HEMTT.

The prediction delta statistics for the Zil-135 can be found in Table 22. With Fidelity 2 implemented, the tendency was for the mean and standard deviation to increase relative to the Fidelity 1 statistics.

Table 22. Zil-135 {Climate Zone 6, Cross-Country, Dry}.

Fidelity 1		Fidelity 2	
	Dry		Dry
Mean	-0.67	Mean	-1.54
Standard Deviation	2.79	Standard Deviation	3.43
Range	25.24	Range	23.99
Minimum	-20.43	Minimum	-20.43
Maximum	4.81	Maximum	3.56
Count	26928	Count	26928

All units are mph except for "Count"

Figure 46 and Figure 47 plot over, under, and even-predictions. Figure 46 indicates that very few over-predictions are made between these two vehicles while significant portions have even-predictions. Figure 47 confirms this, indicating that approximately 60 percent of the data points have even predictions (with 93.3 percent of Fidelity 1 data points less than 5 mph and 86.2 percent of Fidelity 2 data points less than 5 mph). In addition, 95 percent of the data points are within ±6.67 mph for Fidelity 1 and ±8.9 mph for Fidelity 2.

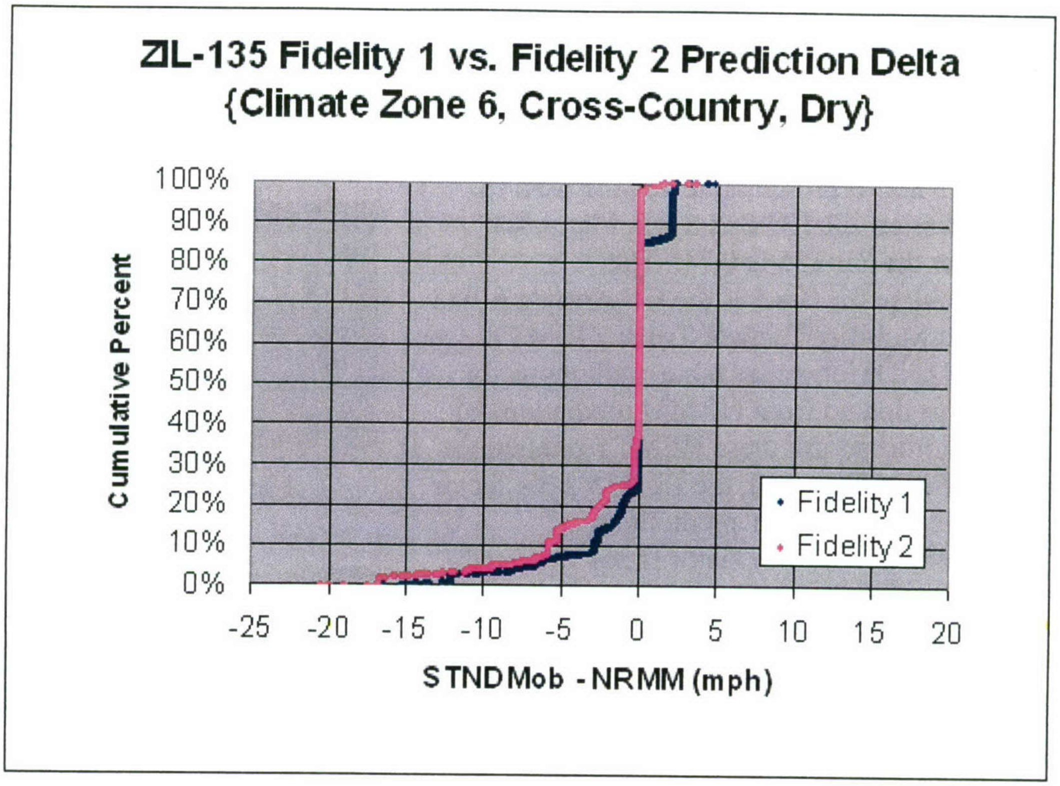


Figure 46. Zil-135 Fidelity 1 vs. Fidelity 2 Prediction Delta {Climate Zone 6, Cross-Country, Dry}.

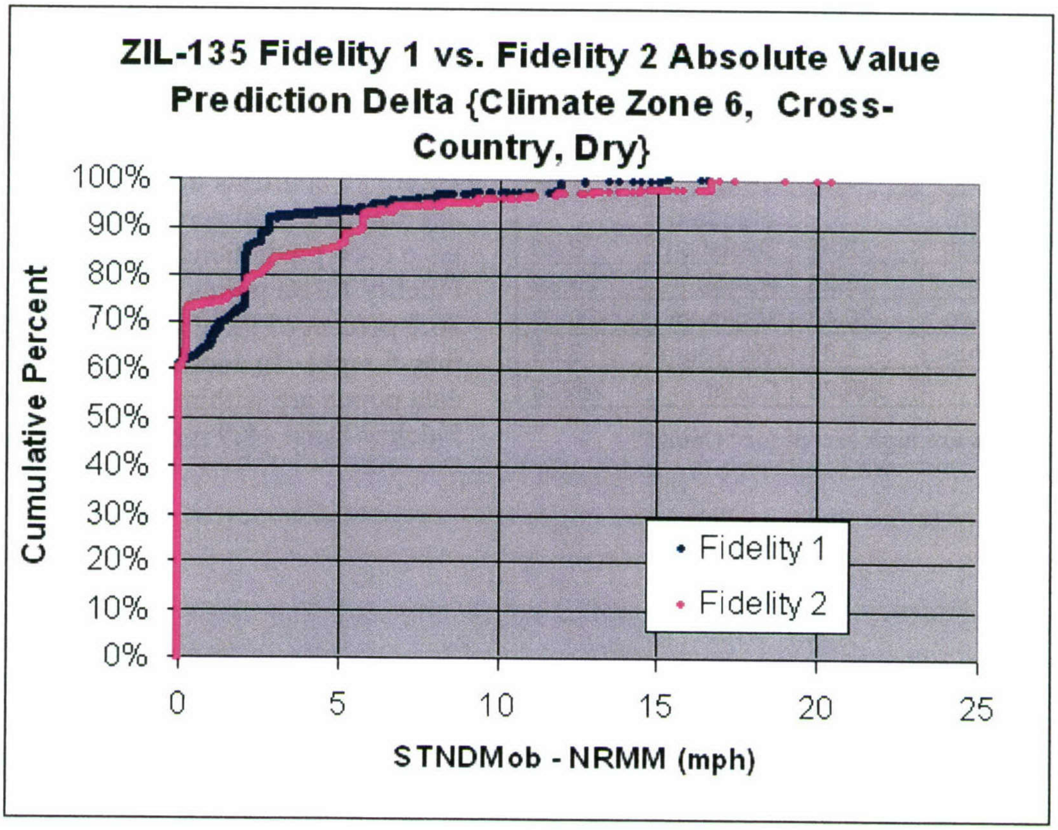


Figure 47. Zil-135 Fidelity 1 vs. Fidelity 2 Absolute Value Prediction Delta {Climate Zone 6, Cross-Country, Dry}.

The reason for the significant number of even-predictions is due to the limited mobility of these vehicles. Basically, these are relatively large wheeled vehicles with limited mobility when faced with significant obstacles and soft soils. Fifty percent of the cross-country terrain units examined have obstacles too narrow for these vehicles to maneuver in (i.e., obstacle spacing 25 ft or less produces a NOGO situation). Subsequently, the speeds on these terrains are zero due to the maneuver NOGO situation. In addition, one quarter of the terrain units in the cross-country terrain have obstacles (i.e., 30 ft obstacle spacing) that allow very limited maneuverability for these vehicles, thereby forcing low speeds (approximately 6.67 mph or less) and, thus, small prediction deltas. The remaining terrain units produce points in Figure 48 that are not lying directly on the x or y axis, or very close to the origin.

Although a small data set produces the scatter shown in the figure, some aspects of the figure are still worthy of note. First, the horizontal line at approximately 18 mph (Fidelity 1) is a HEMTT speed limitation due to vehicle ride. Second, it appears from the data that Fidelity 1 produces a more accurate representation of the Zil-135 than Fidelity 2, thus the predictions would have been more accurate if the bin factor had never been applied. This situation is caused by several factors. One factor is that the bin factor methodology is not always the most accurate method for adjusting the Fidelity 1 predictions. In particular, for relatively slow, less mobile vehicles, the methodology will sometimes produce results like these since the bin factor is based on top speed. For slow, less mobile, vehicles, top speed is likely not the best single comparison element for calculating the bin factor.

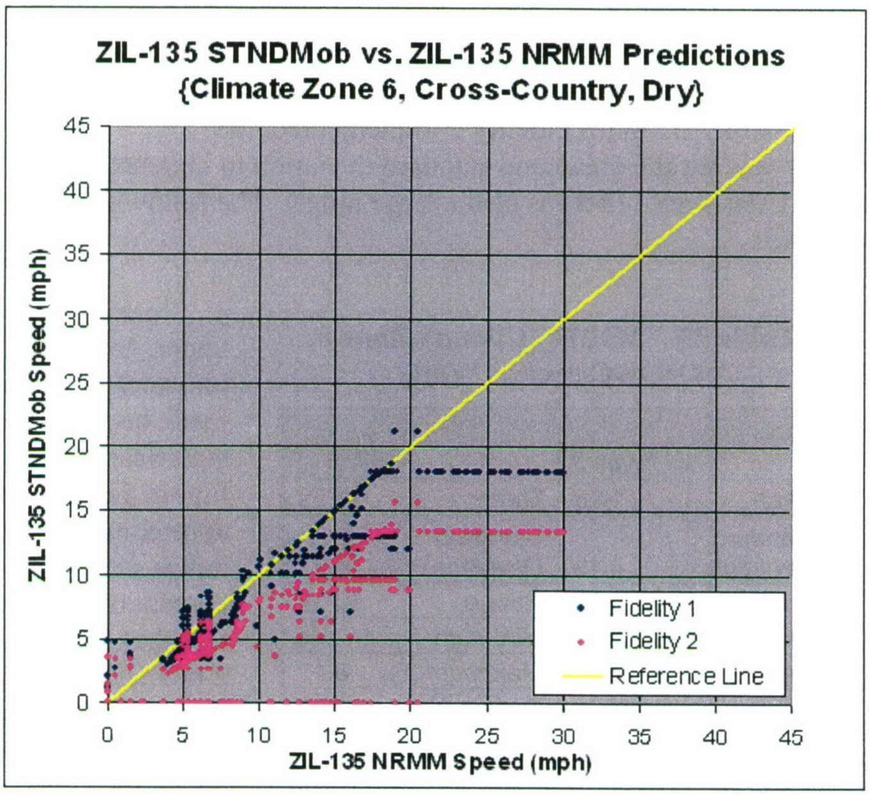


Figure 48. Zil-135 Fidelity 1 vs. Fidelity 2 Predictions {Climate Zone 6, Cross-Country, Dry}.

Another factor is the terrain. In this case, a road terrain may have produced increased prediction accuracy for Fidelity 2 since top speed would have been more of a representative factor. With that said, overall the vehicles compare well and, as stated previously, the methodology appears to produce results that have low prediction deltas.

5.0 Bin 6 – Low Mobility Wheeled.

The Bin 6 non-representative vehicle used for this test is the U.S. Army's M1074 Palletized Load System (PLS), Figure 49. The bin factor for the M1074 is 0.85. The representative vehicle for Bin 6 is the U.S. Army's M917 6x6 Dump Truck, Figure 50. All STNDMob speed table predictions for Bin 6 therefore originated from NRMM predictions of the M917. In order to use these M917 predictions to represent the M1074's speed, the M1074's bin factor (0.85) is applied to the M917 predictions when using Fidelity 2. The bin factor is not applied when using Fidelity 1. All tests were performed using Climate Zone 8, Humid Microthermal Climates (e.g., Humid Continental, Warm Summer), with no interpolation. The scenario was set at Cross-Country – Wet.

Figure 50. M1074/PLS.

Figure 49. M917.

The prediction delta statistics for the M1074 can be found in Table 23. With Fidelity 2 implemented, the tendency was for the mean and standard deviation to increase, albeit minimally, relative to the Fidelity 1 statistics. There is also a large range. The following paragraphs will discuss this in more detail.

Table 23 . M1074 {Climate Zone 8, Cross-Country, Wet}.

Fidelity 1		Fidelity 2	
	Wet		Wet
Mean	-1.28	Mean	-1.58
Standard Deviation	4.13	Standard Deviation	4.27
Range	51.2	Range	50.12
Minimum	-44	Minimum	-44
Maximum	7.20	Maximum	6.12
Count	26928	Count	26928

All units are mph except for "Count"

Figure 51 and Figure 52 plot over, under, and even-predictions. Figure 51 indicates that very few over-predictions are made between these two vehicles while significant portions have even-predictions. Figure 52 confirms this, indicating that approximately 60 percent of the prediction deltas were even predictions (with 85.1 percent of Fidelity 1 prediction deltas being less than 5 mph and 86.0 percent of Fidelity 2 prediction deltas being less than 5 mph). In addition, 95 percent of the data points are within ±8.51 mph for Fidelity 1 and ±9.68 mph for Fidelity 2.

The reason for the significant number of even-predictions is due to the limited mobility of these vehicles. Basically, these are relatively large wheeled vehicles with limited mobility when faced with significant obstacles and soft soils. Fifty percent of the cross-country terrain units examined have obstacles too narrow for these vehicles to maneuver in (i.e., obstacle spacing 25 ft or less produces a NOGO situation). Subsequently, the speeds on these terrains are zero due to the maneuver NOGO situation.

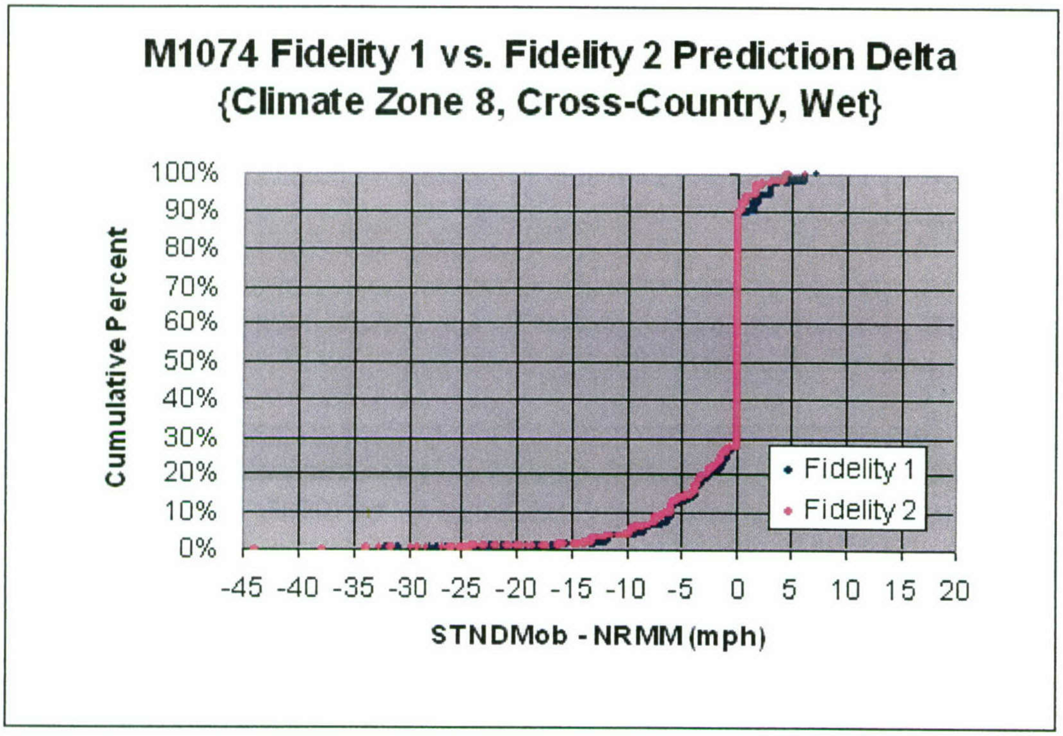


Figure 51. M1074 Fidelity 1 vs. Fidelity 2 Prediction Delta {Climate Zone 8, Cross-Country, Wet}.

Also of interest is the prominent horizontal line for the M917 at 12 mph (Fidelity 1) shown in Figure 53. These lines are caused by a vehicle ride limit imposed at 12 mph for the M917 on the associated terrains (i.e., terrains with a .6 rms). This is also the cause for the large ranges shown in Table 1, since the M1074 ride limitation on the same terrain is <u>much</u> greater at 44 mph. A final aspect of Figure 53 to note is the vertical line that occurs at 5.98 mph. This line accounts for one quarter of the tested terrain units (terrain units with an obstacle spacing of 30 ft.). The top maneuver speed for the M1074 around these obstacles is 5.98 mph. The M917, a shorter and more maneuverable vehicle, can attain a slightly faster speed at 12 mph on the same terrain. Therefore, the vertical line is formed due to the M1074's obstacle (30 ft spacing) speed limitation (5.98 mph) and the M917's ride (.6 rms) speed limitation (12 mph). With that said, overall the vehicles compare well and, as stated previously, the methodology produces results that have low prediction deltas.

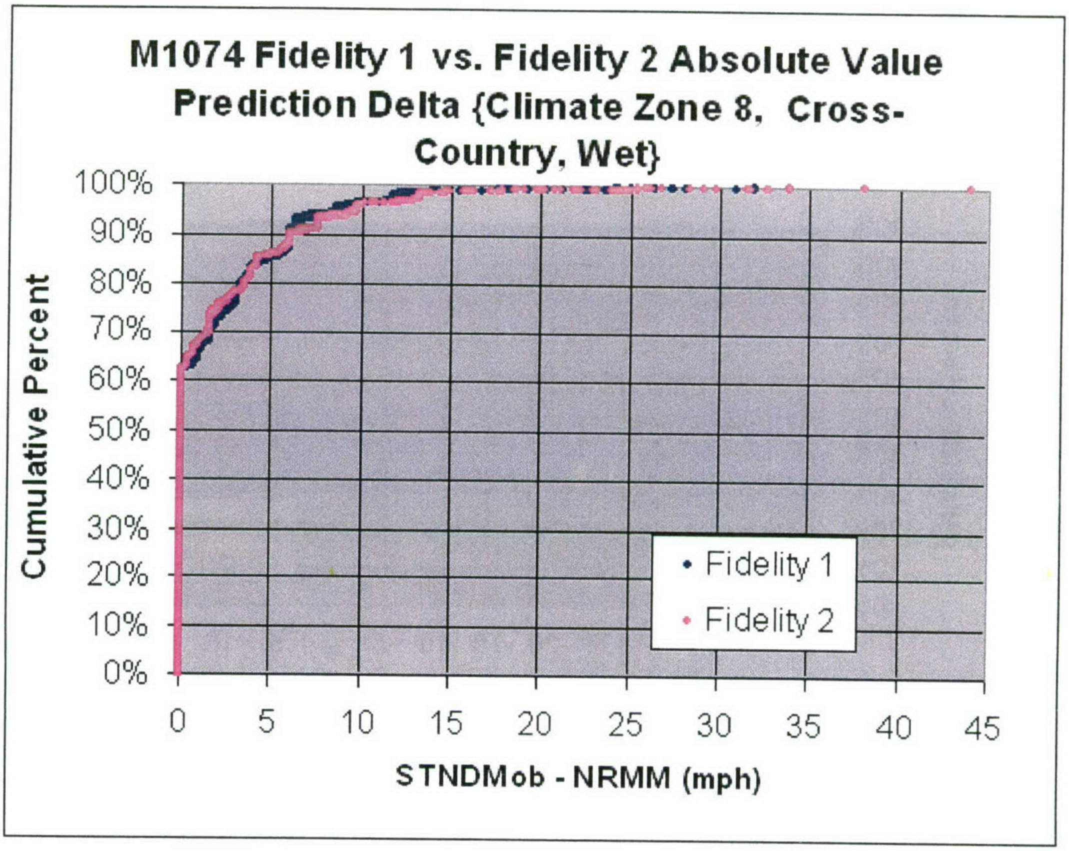


Figure 52. M1074 Fidelity 1 vs. Fidelity 2 Absolute Value Prediction Delta {Climate Zone 8, Cross-Country, Wet}.

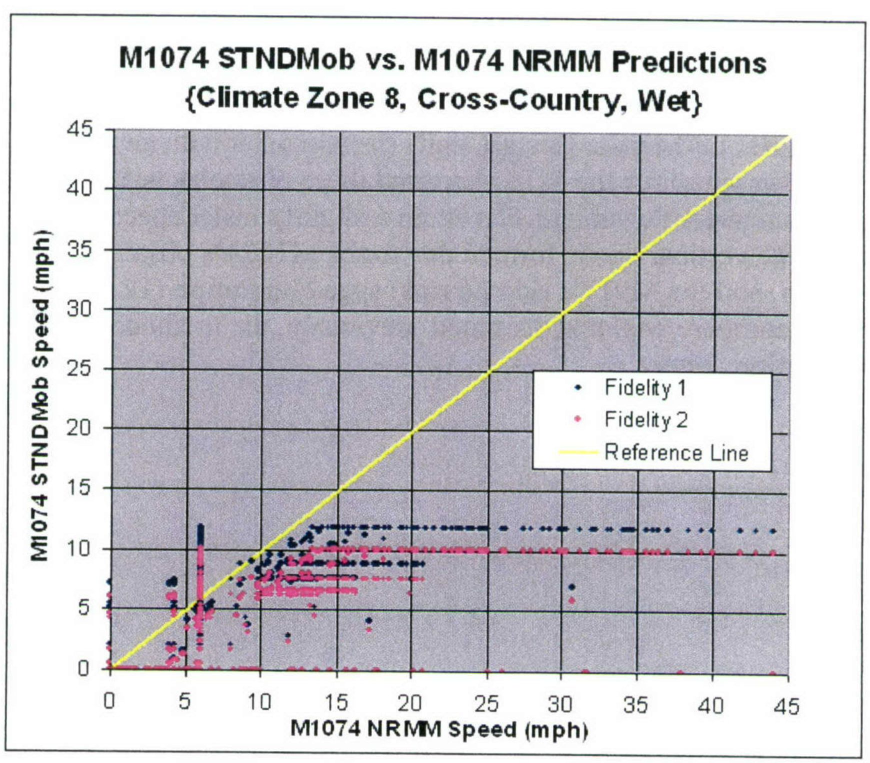


Figure 53. M1074 Fidelity 1 vs. Fidelity 2 Predictions {Climate Zone 8, Cross-Country, Wet}.

6.0 Bin 7 – High Mobility Wheeled with Trailer.

The Bin 7 non-representative vehicle used for this test is the U.S. Army's M923 5-Ton Truck with an M200A1 trailer, Figure 54. The bin factor for the M923/M200A1 is 0.89. The representative vehicle for Bin 7 is the U.S. Army's M1084 Medium Tactical Vehicle (MTV) with the M1095 Trailer, Figure 55. All STNDMob speed table predictions for Bin 7 therefore originated from NRMM predictions of the MTV/M1095. In order to use these MTV/M1095 predictions to represent the M923's speed, the M923's bin factor (0.89) is applied to the MTV/M1095 predictions when using Fidelity 2. The bin factor is not applied when using Fidelity 1. All tests were performed using Climate Zone 13, Undifferentiated Highlands, with no interpolation. The scenario was set at Road – Snow.

Figure 54. M923 5-Ton Truck with M200A1 Trailer.

Figure 55. M1084/MTV with M1095 Trailer.

The prediction delta statistics for the M923/M200A1 can be found in Table 24. With Fidelity 2 implemented, the tendency was for the mean and standard deviation to increase relative to the Fidelity 1 statistics. One other aspect of note is the data point count. With only 108 data points, the subsequent figures will appear to be more segmented. In a snow environment, road terrain does not include trails, thus causing the reduced number of data points relative to a dry or wet environment.

Table 24. M923 {Climate Zone 13, Road, Snow}.

Fidelity 1		Fidelity 2	
	Snow		Snow
Mean	0.5	Mean	-2.1
Standard Deviation	5.6	Standard Deviation	5.8
Range	27.7	Range	28.5
Minimum	-15.0	Minimum	-19.4
Maximum	12.7	Maximum	9.1
Count	108	Count	108

All units are mph except for "Count"

Figure 56 and Figure 57 depict over, under, and even-predictions. Referring to Figure 57 it can be seen that 80.6 percent of Fidelity 1 prediction deltas, and 72.2 percent of Fidelity 2 prediction deltas are within 5 mph. In addition, 95 percent of the data points are within ±12.7 mph for Fidelity 1 and ±10.03 mph for Fidelity 2. The terrain examined is purely road, thus there are no NOGO situations.

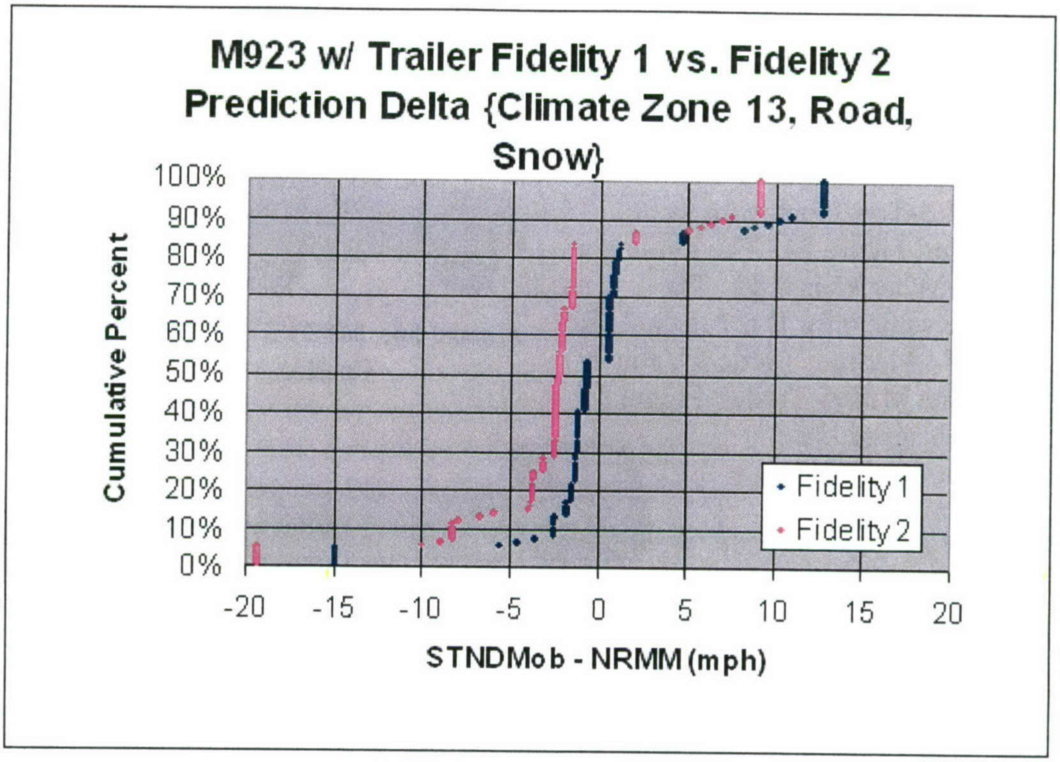


Figure 56. M923/M200A1 Fidelity 1 vs. Fidelity 2 Prediction Delta {Climate Zone 13, Road, Snow}.

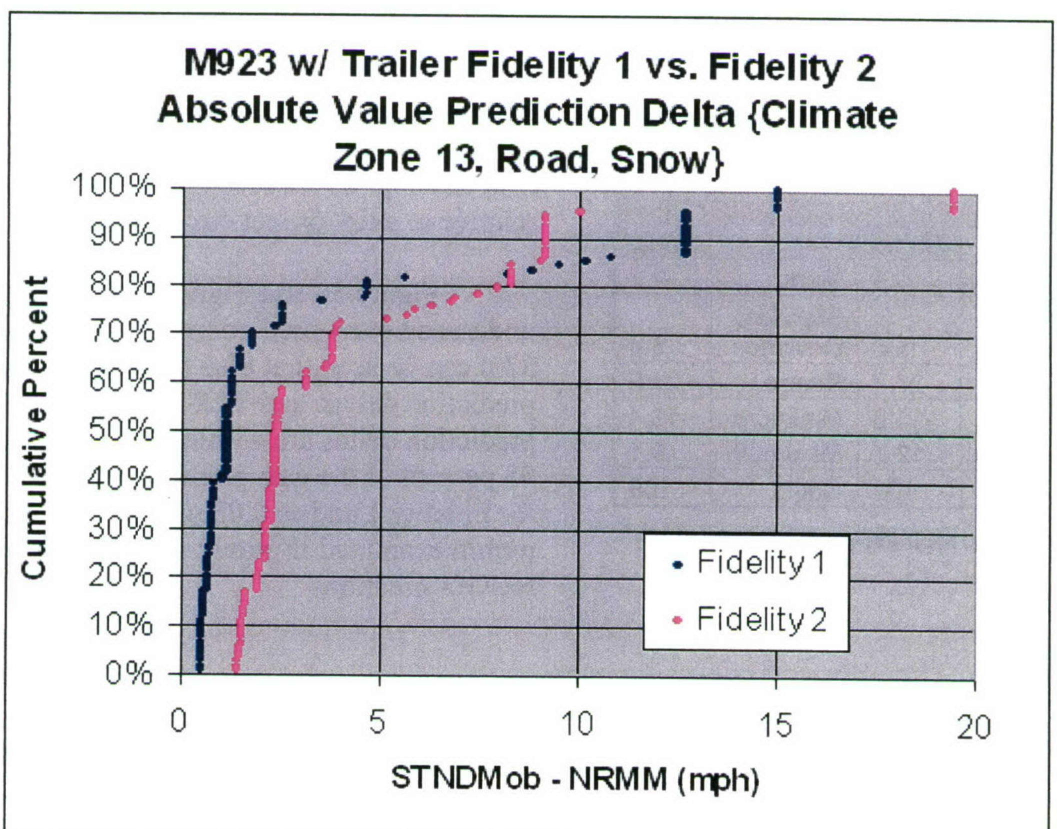


Figure 57. M923/M200A1 Fidelity 1 vs. Fidelity 2 Absolute Value Prediction Delta {Climate Zone13, Road, Snow}.

Figure 58 shows that many of the data points lie just on either side of the reference line. There are two items that are worthy of note. The first, the vertical line occurring at 19.3 mph and the horizontal lines occurring at 40 mph (Fidelity 1) and 35.6 mph (Fidelity 2). Both lines are produced due to vehicle ride limitations of the M923 (Vertical Line) and the MTV (Horizontal Lines) as was seen in previous bins. The second item of note is the maximum speed of 55 mph produced for the M923. This is due to tire speed limits imposed on the vehicle within the NRMM vehicle file.

As was seen with other bins, it appears that the Fidelity 1 predictions more accurately represent the M923/M200A1 than the Fidelity 2 predictions. As discussed previously, this is due to the bin factor methodology not always being the most accurate method for predicting speeds. In particular, for these relatively slow, less mobile vehicles, the methodology will sometimes produce results like these since it is based on top speed and for slow, less mobile, vehicles, top speed is likely not the best single comparison because top speed is rarely used. Although a road terrain is used in this case, the additional factor of a Snow environment was employed bringing the vehicle speeds back down from their maximums where a top speed based bin factor would have been more appropriate.

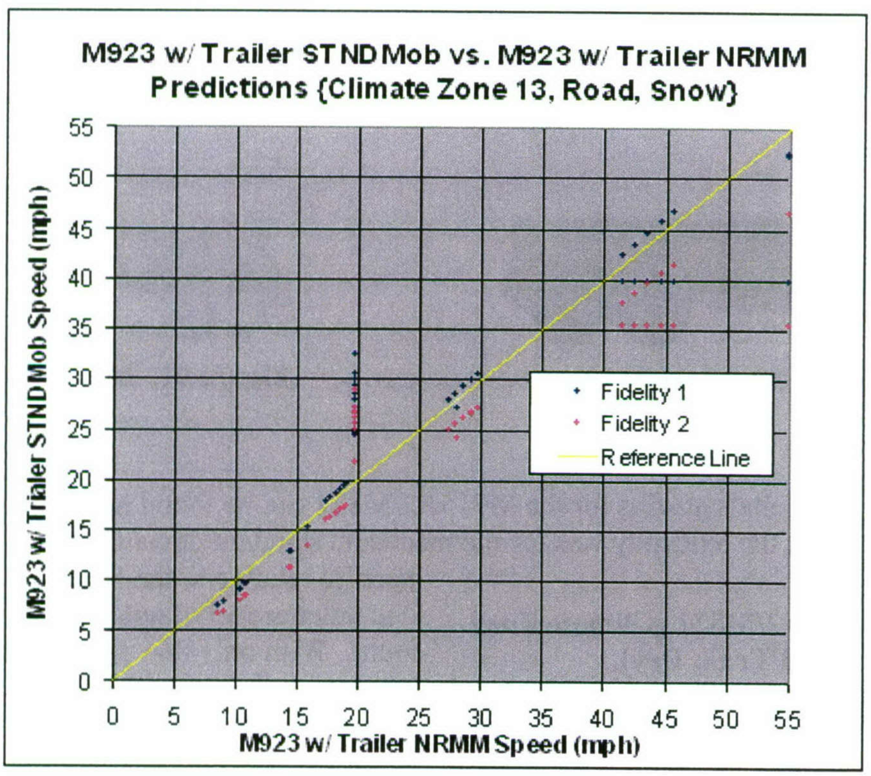


Figure 58. M923/M200A1 Fidelity 1 vs. Fidelity 2 Predictions {Climate Zone 13, Road, Snow}.

7.0 Bin 8 – Medium Mobility Wheeled with Trailer.

The Bin 8 non-representative vehicle used for this test is the U.S. Army's M915A2 6x4 Tractor with the M872 Semi-Trailer, Figure 59. The bin factor for the M915A2/M872 combination is 0.89. The representative vehicle for Bin 8 is the U.S. Army's M985 Heavy Expanded Mobility Tactical Truck (HEMTT), Figure 60, with the M989A1 Heavy Equipment Mobile Ammunition Trailer (HEMAT) Trailer, Figure 61. All STNDMob speed table predictions for Bin 8 therefore originated from NRMM predictions of the HEMTT/M989A1. In order to use these HEMTT/M989A1 predictions to represent the M915A2/M872's speed, the M915A2/M872's bin factor (0.89) is applied to the HEMTT/M989 predictions when using Fidelity 2. The bin factor is not applied when using Fidelity 1. All tests were performed using Climate Zone 4, Dry Climates (e.g., Desert) with no interpolation. The scenario was set at Road/Trail – Dry.

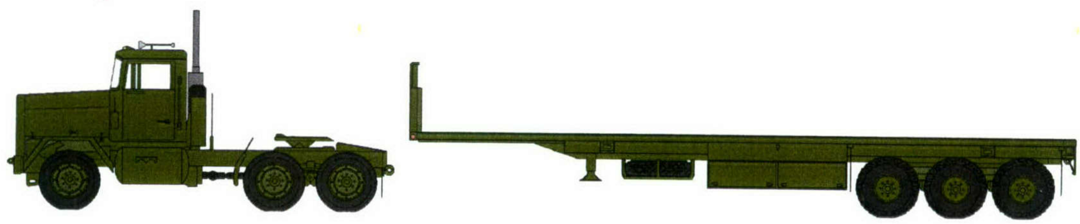


Figure 59. M915A2 Tractor with M872 Semi-Trailer.

Figure 60. M985 HEMTT.

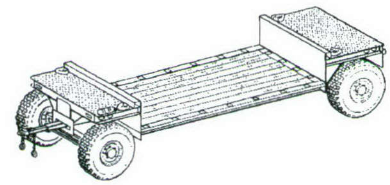


Figure 61. M989A1 Trailer.

The prediction delta statistics for the M915A2/M872 can be found in Table 25. With Fidelity 2 implemented, the tendency was for the mean and standard deviation to slightly increase relative to the Fidelity 1 statistics. One other aspect of note is the data point count. With only 864 data points the subsequent figures will appear to be more segmented than most of the previous bin figures.

Table 25. M915A2/M872 {Climate Zone 4, Road/Trail, Dry}.

Fidelity 1		Fidelity 2	
	Dry		Dry
Mean	2.50	Mean	2.75
Standard Deviation	3.98	Standard Deviation	4.05
Range	25.18	Range	24.98
Minimum	-18.18	Minimum	-17.38
Maximum	7.00	Maximum	7.60
Count	864	Count	864

All units are mph except for "Count"

Figure 62 and Figure 63 provide a picture regarding over, under, and even-predictions. Referring to Figure 63, it can be seen that 64.2 percent of Fidelity 1 prediction deltas, and 64.0 percent of Fidelity 2 prediction deltas are within 5 mph. It should be noted that a significant portion of the data has a prediction delta of approximately 6 mph. A reexamination of the data shows us that 92.7 percent of Fidelity 1 and Fidelity 2 predictions are within this range. In addition, 95 percent of the data points are within ±7 mph for Fidelity 1 and ±7.6 mph for Fidelity 2.

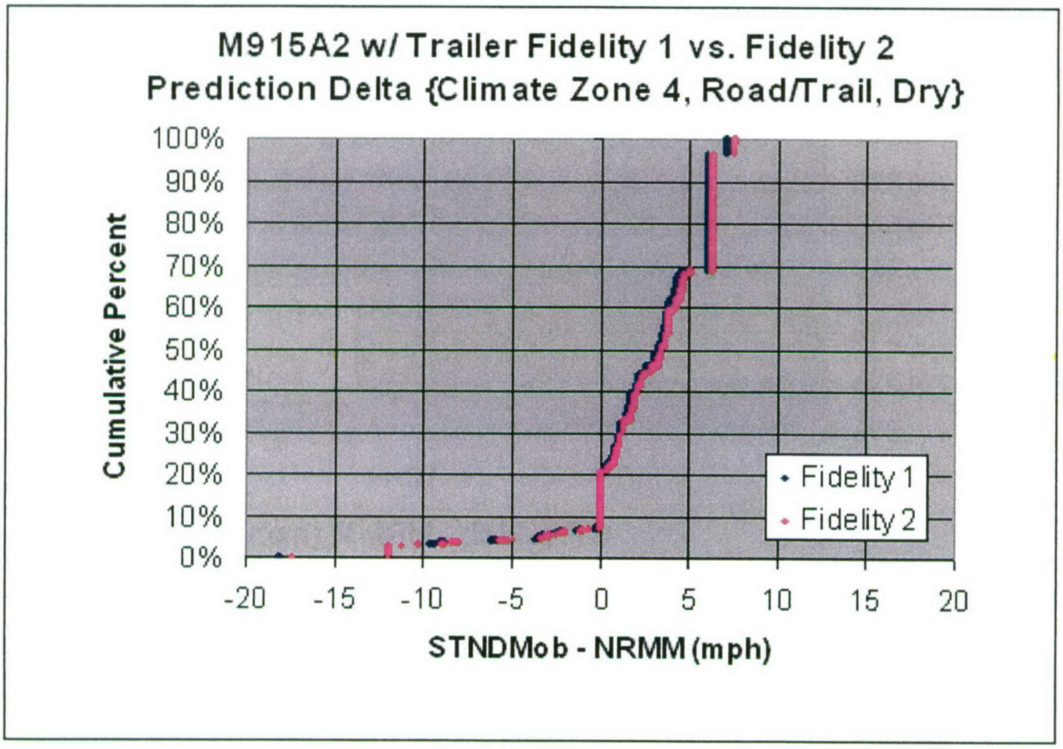


Figure 62. M915A2/M872 Fidelity 1 vs. Fidelity 2 Prediction Delta {Climate Zone 4, Road/Trail, Dry}.

It can also be seen in the two figures that this data set, as compared to Bin 7, has some prediction deltas of zero indicating exact speed matches. These instances occur when both vehicles have NOGO situations and attain zero speed. These situations occur for two reasons. First, on steep upward slopes both vehicles tend to not be able to climb the slope. Second, "trails" are also included in the "dry" road terrains, and trails are unpaved. These vehicles exhibit a NOGO situation when they cannot overcome the resistance of the soil (e.g., soft soil trails).

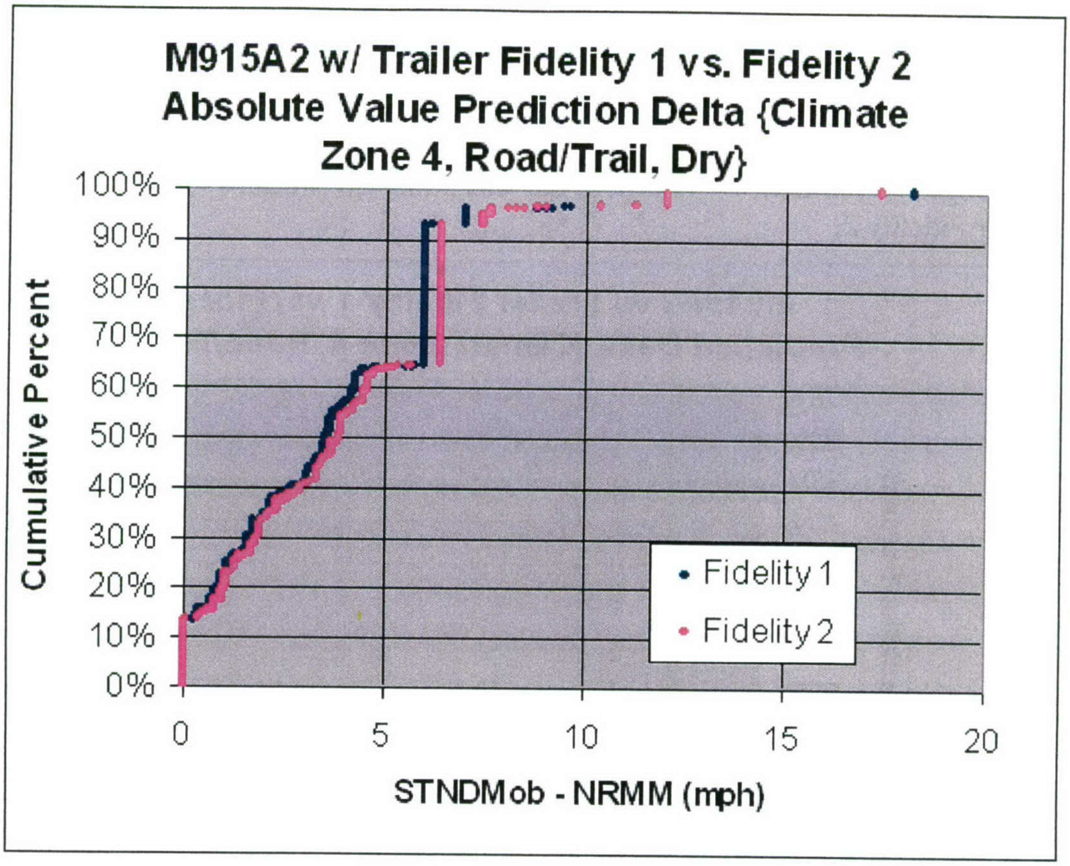


Figure 63. M915A2/M872 Fidelity 1 vs. Fidelity 2 Absolute Value Prediction Delta {Climate Zone 4, Road/Trail, Dry}.

In Figure 64, many of the data points lay just on either side of the reference line. The vertical lines are, again, caused by vehicle ride limitations imposed on the M915A2 in the NRMM vehicle file. In addition, it can be seen that Fidelity 1 and 2 provide very consistent results as would be expected for limited mobility vehicles on dry roads.

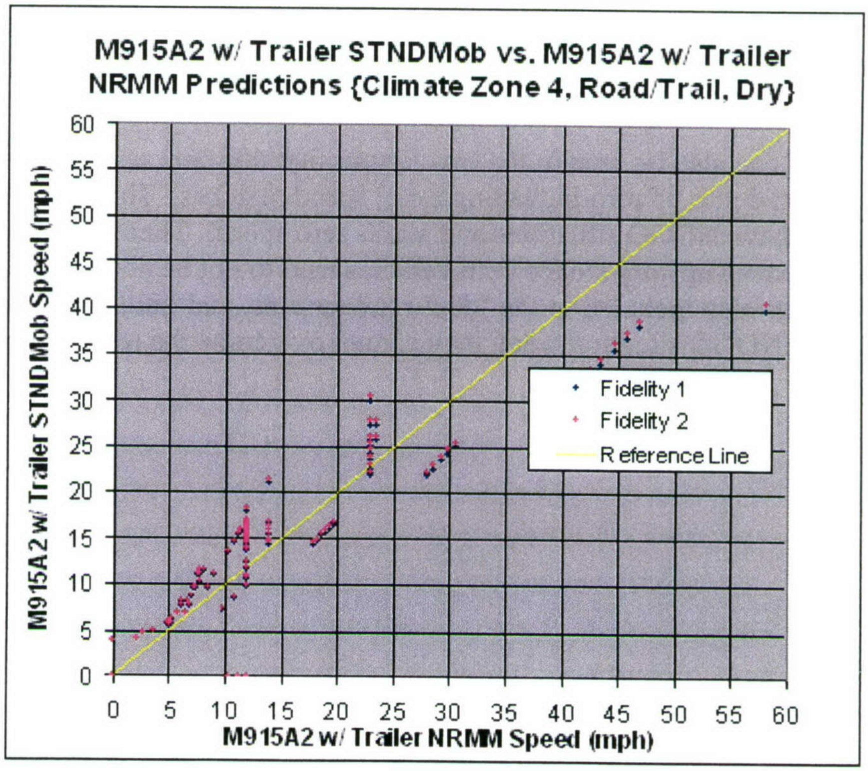


Figure 64. M915A2/M872 Fidelity 1 vs. Fidelity 2 Predictions {Climate Zone 4, Road/Trail, Dry}.

8.0 Bin 9 – Low Mobility Wheeled with Trailer.

The Bin 9 non-representative vehicle used for this test is the U.S. Army's M1070 Heavy Equipment Transporter (HET) with the M1000 Semi-Trailer, Figure 65. The bin factor for the M1070/M1000 is 1.0. The representative vehicle for Bin 9 is the U.S. Army's M911 Commercial Heavy Equipment Transporter (HET-C) with the M747 Trailer, Figure 66. All STNDMob speed table predictions for Bin 9 therefore originated from NRMM predictions of the M911/M747. In order to use these M911/M747 predictions to represent the M1070/M1000's speed, the M1070/M1000's bin factor (1.0) is applied to the M911/M747 predictions when using Fidelity 2. The bin factor is not applied when using Fidelity 1. All tests were performed using Climate Zone 6, Humid Mesothermal Climates (e.g., Humid Subtropical) with no interpolation. The scenario was set at Road/Trail – Wet.

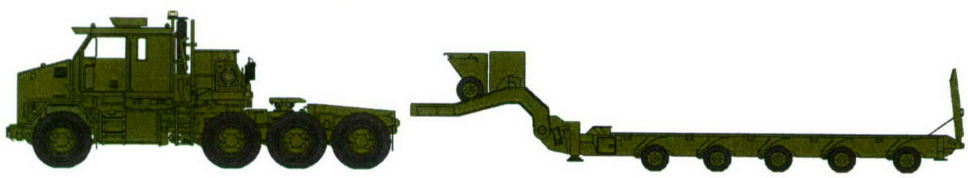


Figure 65. M1070 HET with M1000 Semi-Trailer.

Figure 66. M911 HET-C with M747 Semi-Trailer.

The prediction delta statistics for the M1070/M1000 can be found in Table 26. With Fidelity 2 implemented, the mean and standard deviation show no change relative to the Fidelity 1 statistics. This is due to the bin factor for the M1070/M1000 being 1, thereby no change to the data is made between Fidelity 1 and Fidelity 2.

Figure 67 and Figure 68 provide a clearer picture regarding over, under, and even-predictions. It should be first noted that data for Fidelity 1 do not seem to be plotted. In fact, due to the bin factor of 1.0, the data sets are identical. All Fidelity 2 values lie directly on top of the Fidelity 1 values obscuring the data points.

Table 26. M1070/M1000 {Climate Zone 6, Road/Trail, Wet}.

Fidelity 1		Fidelity 2	
	Wet		Wet
Mean	0.95	Mean	0.95
Standard Deviation	3.44	Standard Deviation	3.44
Range	30.01	Range	30.01
Minimum	-19.00	Minimum	-19.00
Maximum	11.01	Maximum	11.01
Count	864	Count	864

All units are mph except for "Count"

Referring to Figure 68 it can be seen that 91.7 percent of Fidelity 1 and Fidelity 2 prediction deltas are less than 5 mph. In addition, 95 percent of the data points are within ±10.14 mph for Fidelities 1 and 2.

There are some prediction deltas of zero indicating exact speed matches (similar to Bin 8). These instances occur when both vehicles have NOGO situations and attain zero speed. These situations occur for two reasons. First, on upward slopes both vehicles tend to not be able to climb the slope. Second, because "trails" are also included in the road terrains and trails are unpaved, these vehicles sometime have a NOGO situation when they cannot overcome the resistance of the soil.

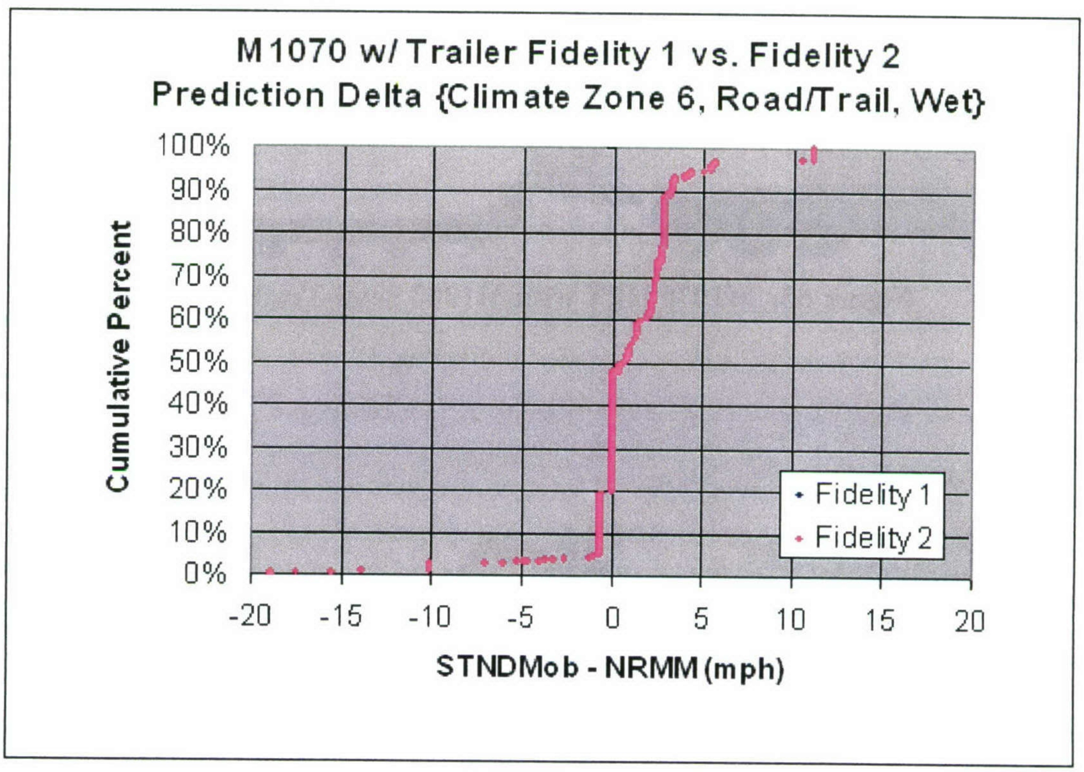


Figure 67. M1070/M1000 Fidelity 1 vs. Fidelity 2 Prediction Delta {Climate Zone 6, Road/Trails, Wet}.

Figure 69 shows that many of the data points lie just on either side of the reference line. The horizontal lines are, again, caused by vehicle ride limitations imposed on the M911 in the NRMM vehicle file.

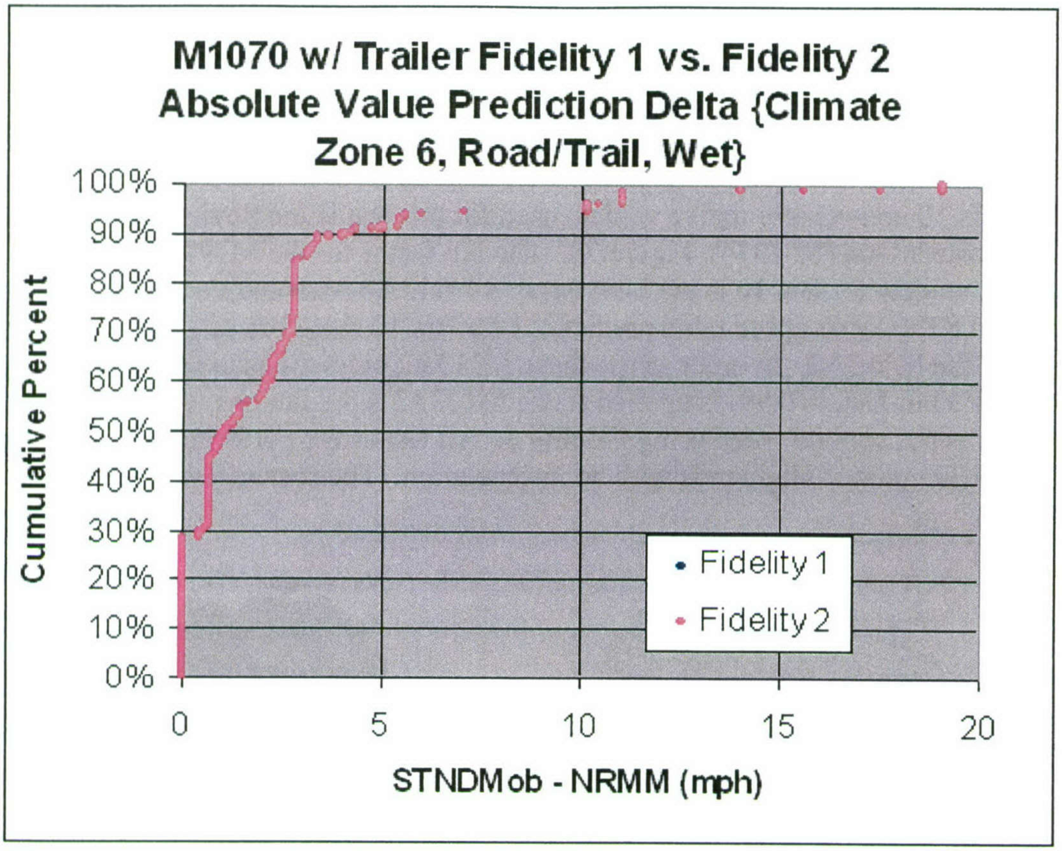


Figure 68. M1070/M1000 Fidelity 1 vs. Fidelity 2 Absolute Value Prediction Delta {Climate Zone 6, Road/Trails, Wet}.

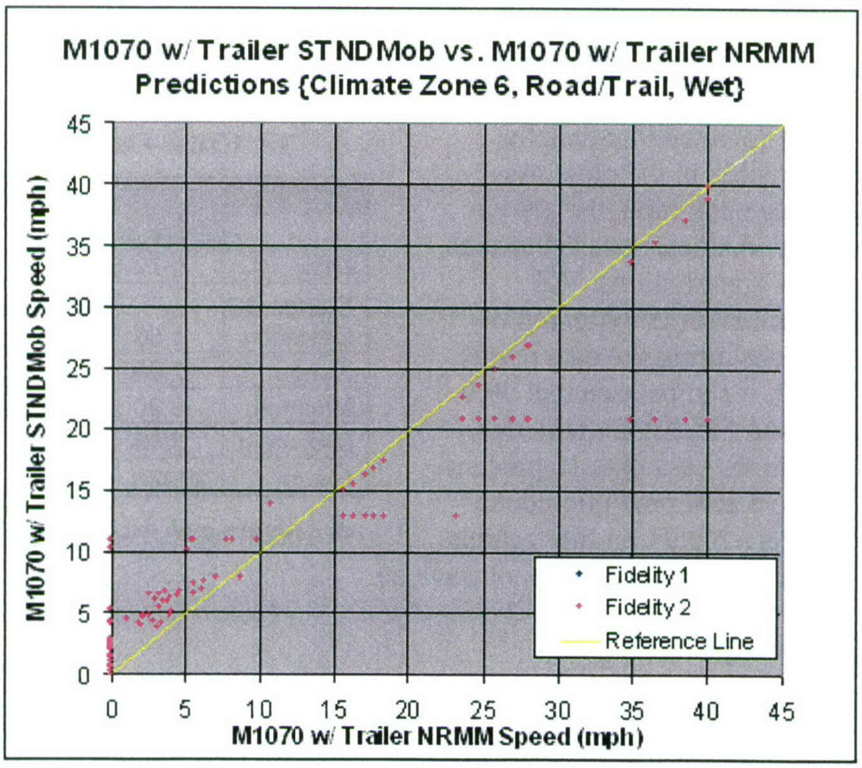


Figure 69. M1070/M1000 Fidelity 1 vs. Fidelity 2 Predictions {Climate Zone 6, Road/Trails, Wet}.

9.0 Bin 10 – Amphibious Combat Vehicle Tracked.

The Bin 10 non-representative vehicle used for this test is the Soviet 2S1, 122 MM, Self-Propelled Howitzer Gun (M-1974), Figure 70. The bin factor for the M1974 is 0.99. The representative vehicle for Bin 10 is the U.S. Army's M113A2 Armored Personnel Carrier (APC), Figure 71. All STNDMob speed table predictions for Bin 10 therefore originated from NRMM predictions of the M113A2. In order to use these M113A2 predictions to represent the 2S1's speed, the 2S1's bin factor (0.99) is applied to the M113A2's predictions when using Fidelity 2. The bin factor is not applied when using Fidelity 1. All tests were performed using Climate Zone 13, Undifferentiated Highlands with no interpolation. The scenario was set at Cross-Country – Dry.

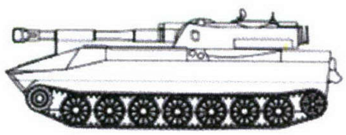


Figure 70. M-1974 2S1.

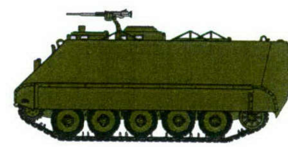


Figure 71. M113A2 APC.

The prediction delta statistics for the 2S1 can be found in Table 27. With Fidelity 2 implemented, the mean shows a minor increase with the standard deviation indicating a minor decrease relative to the Fidelity 1 statistics. This insignificant change is due to the 2S1's bin factor of 0.99, thus very little change to the predicted speeds is made between Fidelity 1 and Fidelity 2.

Figure 72 and Figure 73 provide a clearer picture regarding over, under, and even-predictions. It should be noted that data for Fidelity 1 are barely visible in the plots. As noted in the proceeding paragraph, the .99 bin factor results in nearly identical speeds between Fidelity 1 and Fidelity 2 predictions. All Fidelity 2 values lie almost directly on top of the Fidelity 1 values, obscuring the data points. Referring to Figure 73, it can be seen that 99.9 percent of Fidelity 1 and Fidelity 2 prediction deltas are less than 5 mph. Less than 10 percent of the data points have a zero prediction delta because the M113A2 is a highly mobile vehicle that infrequently encounters terrain it cannot traverse.

Table 27. 2S1 M-1974 {Climate Zone 13, Cross-Country, Dry}.

Fidelity 1		Fidelity 2	
	Dry		Dry
Mean	-0.77	Mean	-0.83
Standard Deviation	1.56	Standard Deviation	1.51
Range	12.65	Range	12.51
Minimum	-9.20	Minimum	-9.45
Maximum	3.45	Maximum	3.06
Count	26928	Count	26928

All units are mph except for "Count"

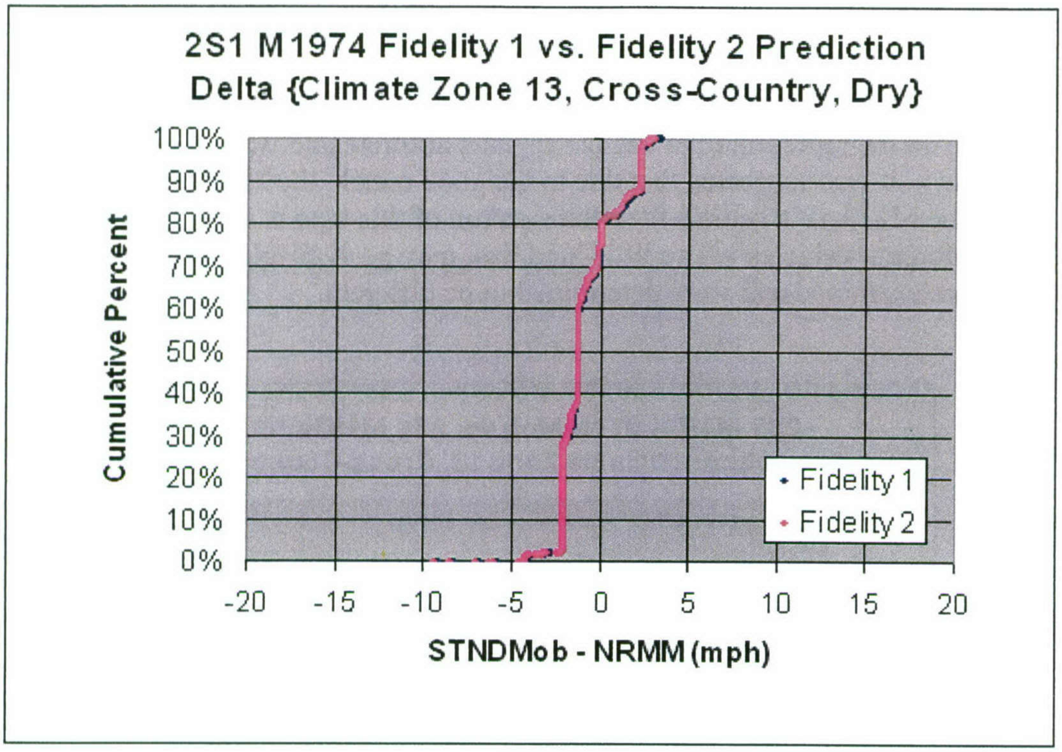


Figure 72. 2S1 M-1974 Fidelity 1 vs. Fidelity 2 Prediction Delta { Climate Zone 13, Cross-Country, Dry }.

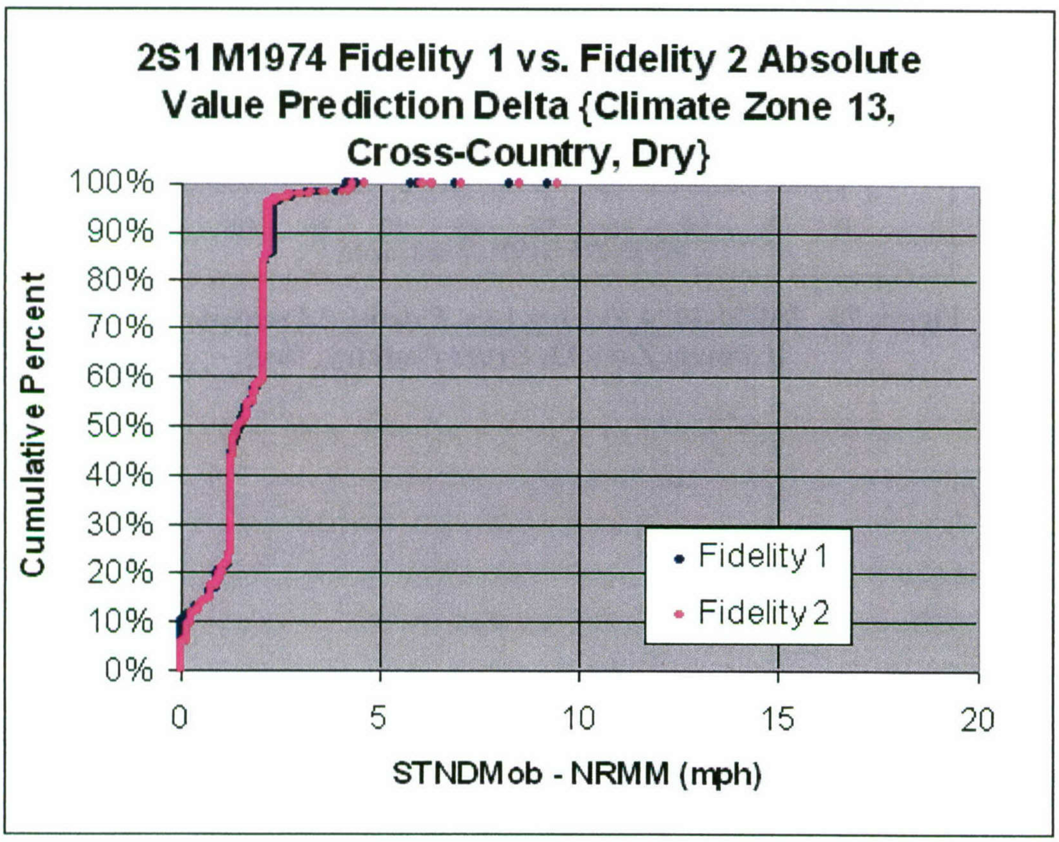


Figure 73. 2S1 M-1974 Fidelity 1 vs. Fidelity 2 Absolute Value Prediction Delta { Climate Zone 13, Cross-Country, Dry}.

Figure 74 shows that many of the data points lie just on either side of the reference line. This confirms the Table 27 data that indicates a small mean and narrow standard deviation. The prediction based on the representative vehicle appears accurate and was one of best matches of the samples tested. It was suspected that due to the good match, the 2S1's vehicle file may have been based on the M113A2's vehicle file. Surrogation of this type is sometimes the case, especially with foreign vehicles where little hard data may be available. However, the two vehicle files were examined and were determined to be different.

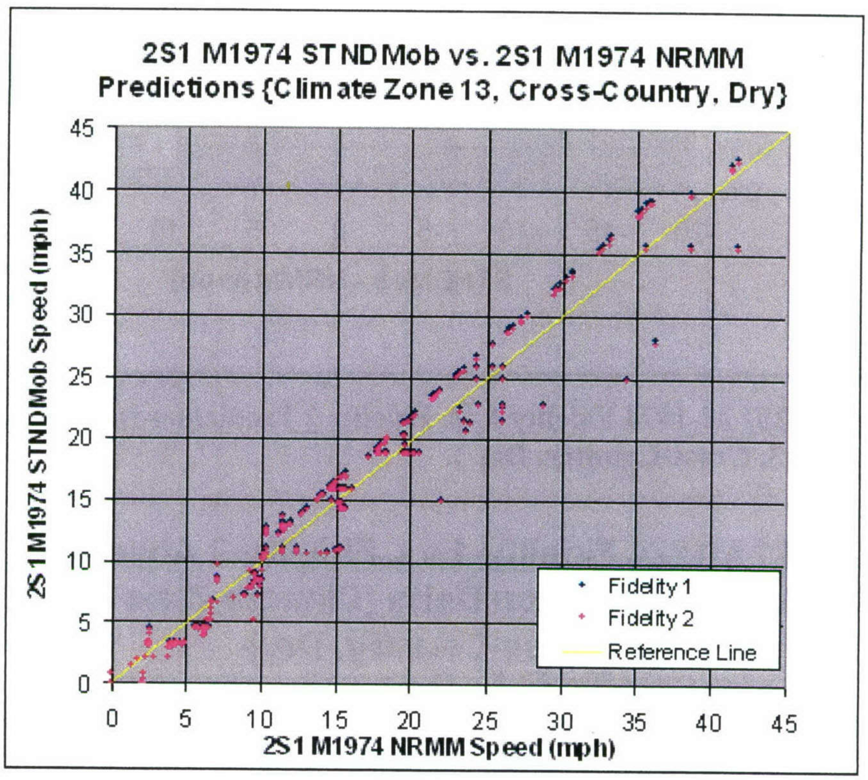


Figure 74. 2S1 M-1974 Fidelity 1 vs. Fidelity 2 Predictions {Climate Zone 13, Cross-Country, Dry}.

10.0 Bin 11 – Amphibious Combat Vehicle Wheeled.

The Bin 11 non-representative vehicle used for this test is the U.S. Army's Stryker Infantry Carrier Vehicle (ICV), Figure 75. The bin factor for the Stryker is 1.0. The representative vehicle for Bin 11 is the U.S. Marine Corp's Light Armored Vehicle-25 (LAV25), Figure 76. All STNDMob speed table predictions for Bin 11 therefore originated from NRMM predictions of the LAV25. In order to use these LAV25 predictions to represent the Stryker's speed, the Stryker's bin factor (1.0) is applied to the LAV25's predictions when using Fidelity 2. The bin factor is not applied when using Fidelity 1. All tests were performed using Climate Zone 8, Humid Microthermal Climates (e.g. Humid Continental, Warm Summer) with no interpolation. The scenario was set at Cross-Country – Wet.

Figure 75. Stryker-ICV.

Figure 76. LAV25.

The prediction delta statistics for the Stryker can be found in Table 28. With Fidelity 2 implemented, the mean and standard deviation show no change, as expected, relative to the Fidelity 1 statistics. This is due to the bin factor for the Stryker being 1.0, thereby no change to the data is made between Fidelity 1 and Fidelity 2.

Figure 77 and Figure 78 depict over, under, and even-predictions. It should be first noted that data for Fidelity 1 are not visible in the plots. In fact, due to the bin factor of 1.0, the data sets are identical. All Fidelity 2 values lie directly on top of the Fidelity 1 values, obscuring the data points. Referring to Figure 78 it can be seen that 94.9 percent of Fidelity 1 and Fidelity 2 prediction deltas are within ±5 mph (95 percent are within ±5.55 mph).

Table 28. Stryker-ICV {Climate Zone 8, Cross-Country, Wet}.

Fidelity 1		Fidelity 2	
	Wet		Wet
Mean	0.04	Mean	0.04
Standard Deviation	2.86	Standard Deviation	2.86
Range	46.38	Range	46.38
Minimum	-34.39	Minimum	-34.39
Maximum	11.99	Maximum	11.99
Count	26928	Count	26928

All units are mph except for "Count"

Figure 78 also shows that 61.7 percent of the data points have zero prediction delta. Due to being wheeled and relatively long, these vehicles have difficulty maneuvering between closely spaced obstacles. Neither vehicle is capable of maneuvering between the obstacles that are spaced at 20 or 25 feet. This means that one half of the terrain tested will have a zero speed associated with it (i.e., NOGO). In addition, the soft wet soils make some portions of the terrain inaccessible.

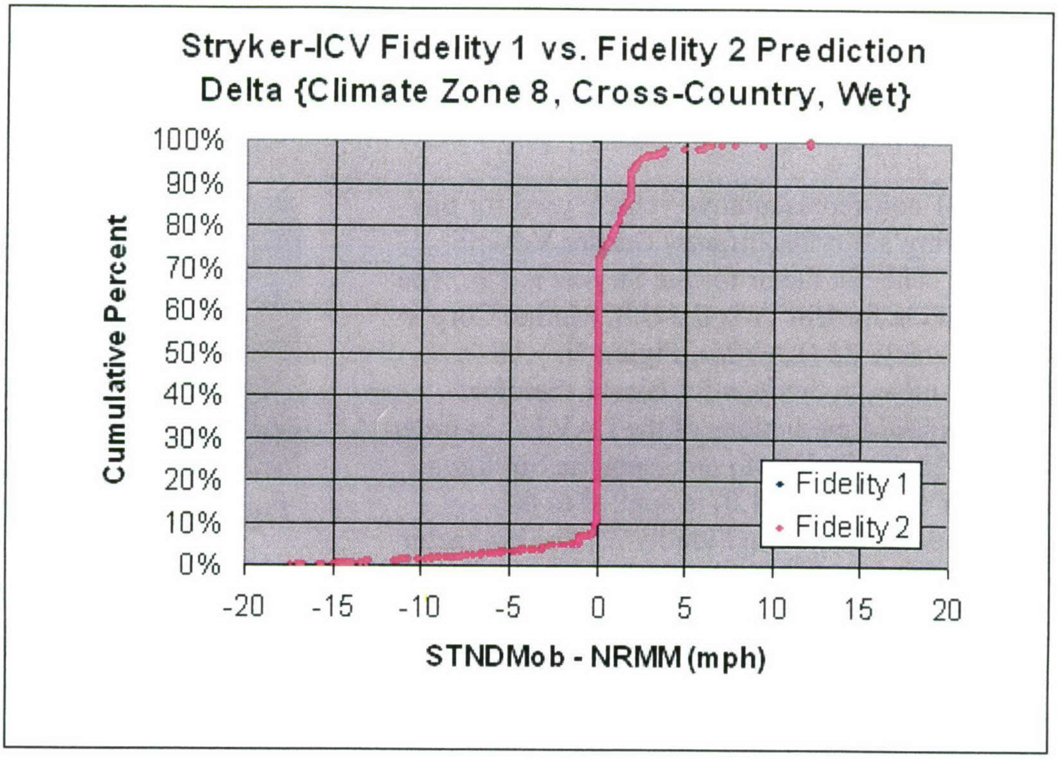


Figure 77. Stryker-ICV Fidelity 1 vs. Fidelity 2 Prediction Delta {Climate Zone 8, Cross-Country, Wet}.

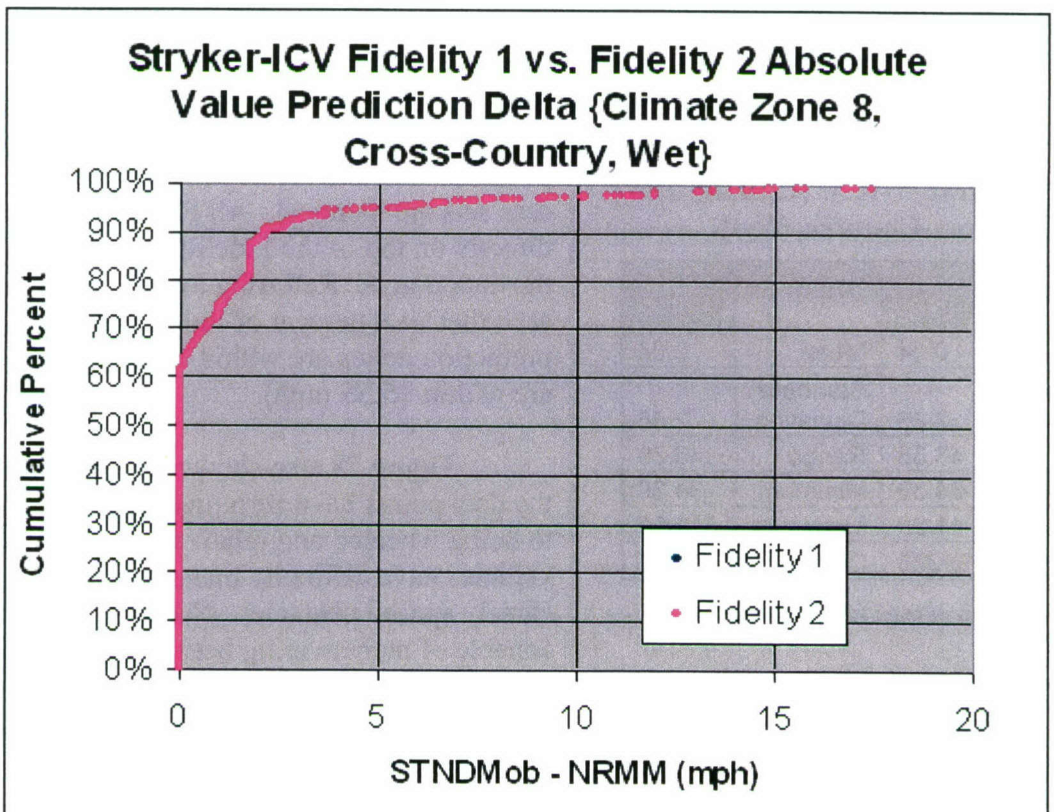


Figure 78. Stryker-ICV Fidelity 1 vs. Fidelity 2 Absolute Value Prediction Delta {Climate Zone 8, Cross-Country, Wet}.

Figure 79 shows that many of the data points lie just on either side of the reference line. This confirms the Table 28 data that indicates a small mean and relatively narrow standard deviation. As was the case for the other wheeled vehicles, the horizontal lines in the figure, and therefore the wide ranges seen in Table 28, are attributed to several factors. Although all horizontal lines were not investigated, it was determined that the vehicle ride limitations imposed in the NRMM vehicle file as well as tire speed limits and visibility restrictions imposed in the NRMM vehicle file were found to cause the majority of the trends. The horizontal lines at 12 mph and 40 mph account for tire speed limits while the horizontal line at 23.5 mph is attributed to vehicle ride limitations. The few data points forming a minor horizontal line at 9.8 mph are due to visibility and occur when the vehicle is going downhill and is unable to brake safely given the visibility restrictions imposed by the terrain.

Based on these findings, the speed predictions calculated using the representative vehicle closely match the NRMM's Stryker-ICV speed predictions on the majority of terrain units..

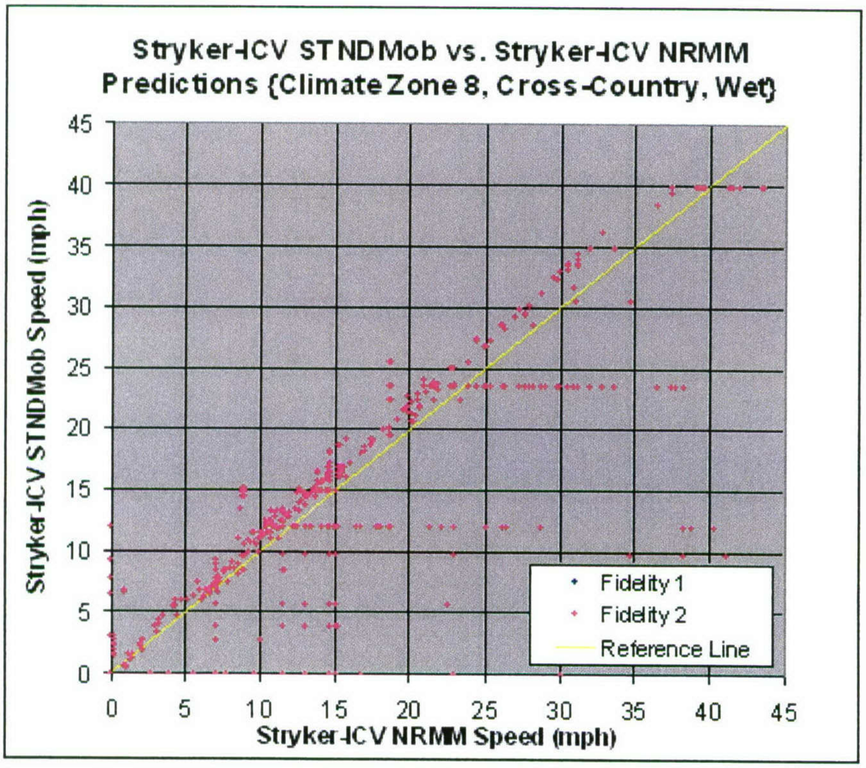


Figure 79. Stryker-ICV Fidelity 1 vs. Fidelity 2 Predictions {Climate Zone 8, Cross-Country, Wet}.

APPENDIX B – BINNING COMPARISON

APPENDIX B – BINNING COMPARISON

As discussed in Section 3.6, a comparison of average NRMM speed difference was made addressing:

- Every terrain unit over six varied terrains
- All twelve representative vehicles

NRMM Speed Difference = | *Vehicle 1 NRMM Speed Prediction – Vehicle 2 NRMM Speed Prediction* |

This appendix will present all six charts pertaining to the NRMM average speed difference and standard deviation comparisons. The chart for terrain 13CD300A, Figure 80, is shown for reference only as it was discussed in detail in Section 3.6 of the main text. As was seen Section 3.6, the LAV25/MTV and M113A2/MLRS speed differences and standard deviations are small. These two pairings are highlighted (in green) throughout the charts in this section to allow for easy comparison.

As a reminder, the terrains being presented are as follows:

- 13CD300A — Undifferentiated Highlands, Cross-Country Terrain, Dry Soil, 300 feet visibility, 150 feet obstacle spacing
- 6CD50B — Undifferentiated Highlands, Cross-Country Terrain, Dry Soil, 50 feet visibility, 30 foot obstacle spacing
- 8CD100A — Humid Microthermal, Cross-Country Terrain, Dry Soil, 100 feet visibility, 150 feet obstacle spacing
- 13CW300A — Undifferentiated Highlands, Cross-Country Terrain, Wet, 300 feet visibility, 150 feet obstacle spacing
- 8CS300A — Humid Microthermal, Cross-Country Terrain, Snow Covered Soil, 300 feet visibility, 150 feet obstacle spacing
- 4RD300A — Dry Climates, Road Terrain, Dry Road, 300 feet visibility, No Obstacles

To read a chart, choose two vehicles for comparison. Find both vehicles on the left side of the chart. The intersection of the row and column is the comparison value for those two vehicles.

Average Prediction Delta (mph)

	Bin 2 (MLRS)	Bin 3 (AVLB)	Bin 4 (MTV)	Bin 5 (M985-10)	Bin 6 (M917)	Bin 7 (MTVM1095)	Bin 8 (M985M989)	Bin 9 (M911M747)	Bin 10 (M113A2)	Bin 11 (LAV25)	Bin 12 (Kawasaki ATV)
Bin 1 (M1A1)	7.26	9.84	10.71	12.42	15.51	10.71	13.97	16.90	8.51	9.37	11.19
Bin 2 (MLRS)		3.71	5.25	7.11	9.69	5.25	8.18	11.08	1.97	5.20	10.56
Bin 3 (AVLB)			3.30	5.22	6.16	3.30	4.69	7.38	2.82	4.79	13.79
Bin 4 (MTV)				3.12	6.24	2.41	4.83	7.63	3.72	1.23	12.79
Bin 5 (M985-10)					3.18	4.58	1.77	4.57	6.09	3.67	15.82
Bin 6 (M917)						5.33	2.07	1.81	8.52	6.54	18.86
Bin 7 (MTVM1095)							3.60	6.36	4.22	3.29	13.92
Bin 8 (M985M989)								2.95	7.03	5.17	17.31
Bin 9 (M911M747)									9.88	7.92	20.21
Bin 10 (M113A2)										4.37	11.75
Bin 11 (LAV25)											12.52

Predicted Delta Standard Deviation

	Bin 2 (MLRS)	Bin 3 (AVLB)	Bin 4 (MTV)	Bin 5 (M985-10)	Bin 6 (M917)	Bin 7 (MTVM1095)	Bin 8 (M985M989)	Bin 9 (M911M747)	Bin 10 (M113A2)	Bin 11 (LAV25)	Bin 12 (Kawasaki ATV)
Bin 1 (M1A1)	7.67	7.67	9.57	12.66	13.54	9.57	11.89	12.98	7.34	11.22	7.93
Bin 2 (MLRS)		3.11	6.09	7.16	8.09	6.09	6.83	7.55	1.63	6.14	6.65
Bin 3 (AVLB)			5.23	5.67	7.31	5.23	6.03	6.73	3.28	5.37	7.36
Bin 4 (MTV)				4.28	5.92	3.80	4.58	6.39	6.17	1.99	7.64
Bin 5 (M985-10)					3.40	4.50	2.94	4.13	6.85	4.19	7.78
Bin 6 (M917)						6.55	2.59	2.46	8.04	5.77	8.51
Bin 7 (MTVM1095)							4.65	6.77	6.38	4.08	8.33
Bin 8 (M985M989)								2.80	6.81	4.63	7.92
Bin 9 (M911M747)									7.45	6.51	8.72
Bin 10 (M113A2)										6.29	6.54
Bin 11 (LAV25)											7.74

Figure 80. Average NRMM Speed Differences and Standard Deviations for Terrain 13CD300A (mph).

Average Prediction Delta (mph)

	Bin 2 (MLRS)	Bin 3 (AVLB)	Bin 4 (MTV)	Bin 5 (M985-10)	Bin 6 (M917)	Bin 7 (MTVM1095)	Bin 8 (M985M989)	Bin 9 (M911M747)	Bin 10 (M113A2)	Bin 11 (LAV25)	Bin 12 (Kawasaki ATV)
Bin 1 (M1A1)	5.15	2.68	2.68	3.48	3.75	2.68	2.68	2.68	6.33	6.30	13.78
Bin 2 (MLRS)		7.78	7.78	2.84	3.23	7.78	7.78	7.78	1.62	3.44	9.36
Bin 3 (AVLB)			0.00	5.09	4.86	0.00	0.00	0.00	8.79	8.08	16.05
Bin 4 (MTV)				3.00	3.20	8.05	8.05	8.05	2.84	0.84	8.15
Bin 5 (M985-10)					1.55	5.09	5.09	5.09	4.06	3.22	10.95
Bin 6 (M917)						4.86	4.86	4.86	4.00	3.22	11.18
Bin 7 (MTVM1095)							0.00	0.00	8.79	8.08	16.05
Bin 8 (M985M989)								0.00	8.78	8.07	16.03
Bin 9 (M911M747)									8.78	8.07	16.03
Bin 10 (M113A2)										2.97	8.71
Bin 11 (LAV25)											8.10

Predicted Delta Standard Deviation

	Bin 2 (MLRS)	Bin 3 (AVLB)	Bin 4 (MTV)	Bin 5 (M985-10)	Bin 6 (M917)	Bin 7 (MTVM1095)	Bin 8 (M985M989)	Bin 9 (M911M747)	Bin 10 (M113A2)	Bin 11 (LAV25)	Bin 12 (Kawasaki ATV)
Bin 1 (M1A1)	1.16	1.16	1.16	2.09	2.83	1.16	1.16	1.16	4.30	4.64	5.84
Bin 2 (MLRS)		3.85	3.85	2.82	3.14	3.85	3.85	3.85	1.17	2.62	4.76
Bin 3 (AVLB)			0.00	3.81	4.58	0.00	0.00	0.00	5.10	6.24	6.91
Bin 4 (MTV)				3.15	2.96	6.44	6.44	6.44	3.50	1.30	6.12
Bin 5 (M985-10)					1.85	3.81	3.81	3.81	3.59	2.84	5.71
Bin 6 (M917)						4.58	4.58	4.58	3.89	2.83	5.90
Bin 7 (MTVM1095)							0.00	0.00	5.10	6.24	6.91
Bin 8 (M985M989)								0.00	5.12	6.25	6.94
Bin 9 (M911M747)									5.12	6.25	6.94
Bin 10 (M113A2)										3.50	5.11
Bin 11 (LAV25)											5.82

Figure 81. Average NRMM Speed Differences and Standard Deviations for Terrain 6CD50B (mph).

Figure 81 was created using terrain 6CD50B. The terrain's obstacle spacing of thirty feet resulted in some vehicles having a complete NOGO situation; therefore, there are several speed predictions of zero.

Average Prediction Delta (mph)

Bin 1 (M1A1)	4.38	7.36	7.85	9.65	12.50	7.85	11.03	13.99	5.64	6.37	9.24
Bin 2 (MLRS)		4.92	5.79	7.83	10.37	5.79	8.90	11.86	1.77	5.31	9.98
Bin 3 (AVLB)			4.01	4.59	5.69	4.01	4.20	6.94	3.66	5.68	12.98
Bin 4 (MTV)				3.44	6.26	2.19	4.93	7.74	4.12	1.66	10.76
Bin 5 (M985-10)					2.87	4.78	1.54	4.36	6.77	4.58	13.89
Bin 6 (M917)						5.27	2.06	1.90	9.02	7.14	16.68
Bin 7 (MTVM1095)							3.65	6.46	4.88	3.54	12.04
Bin 8 (M985M989)								3.00	7.63	5.95	15.20
Bin 9 (M911M747)									10.49	8.76	18.11
Bin 10 (M113A2)										4.72	10.83
Bin 11 (LAV25)											10.69
Bin 12 (Kawasaki ATV)											

Predicted Delta Standard Deviation

Bin 1 (M1A1)	5.72	5.72	6.72	8.86	9.89	6.72	8.13	9.50	5.14	7.65	7.41
Bin 2 (MLRS)		4.01	6.66	7.84	8.87	6.66	7.30	8.21	1.49	6.74	6.75
Bin 3 (AVLB)			5.36	4.97	6.51	5.36	5.22	5.85	3.81	5.74	6.70
Bin 4 (MTV)				4.67	6.45	3.32	4.73	6.80	6.43	2.45	7.16
Bin 5 (M985-10)					2.86	4.51	2.76	3.70	7.32	5.79	6.77
Bin 6 (M917)						6.69	2.44	2.59	8.53	7.50	7.50
Bin 7 (MTVM1095)							4.79	7.24	6.60	3.99	8.37
Bin 8 (M985M989)								2.91	7.04	5.90	7.42
Bin 9 (M911M747)									7.80	7.99	8.19
Bin 10 (M113A2)										6.56	6.54
Bin 11 (LAV25)											6.68
Bin 12 (Kawasaki ATV)											

Figure 82. Average NRMM Speed Differences and Standard Deviations for Terrain 8CD100A (mph).

Figure 82 is very similar to the previous charts except the visibility is 100 feet and the obstacle spacing is back to 150 feet. Again, the LAV25/MTV and M113A2/MLRS are very similar with low speed differences and standard deviations.

Average Prediction Delta (mph)

Bin 1 (M1A1)	6.32	8.67	9.75	11.18	14.49	9.75	13.40	15.57	7.45	8.56	10.59
Bin 2 (MLRS)		3.54	5.25	6.82	9.72	5.25	8.68	10.78	1.78	4.93	9.53
Bin 3 (AVLB)			3.33	4.74	6.29	3.33	5.33	7.25	2.78	4.40	12.37
Bin 4 (MTV)				2.87	6.21	2.66	5.26	7.29	3.51	1.14	11.58
Bin 5 (M985-10)					3.46	4.49	2.51	4.55	5.79	3.34	13.91
Bin 6 (M917)						5.13	1.78	1.71	8.64	6.41	16.99
Bin 7 (MTVM1095)							3.97	6.04	4.37	3.40	12.71
Bin 8 (M985M989)								2.75	7.65	5.51	15.90
Bin 9 (M911M747)									9.70	7.49	18.12
Bin 10 (M113A2)										4.04	10.59
Bin 11 (LAV25)											11.36
Bin 12 (Kawasaki ATV)											

Predicted Delta Standard Deviation

Bin 1 (M1A1)	7.55	7.55	9.10	11.98	13.09	9.10	11.89	12.84	7.15	10.63	8.34
Bin 2 (MLRS)		3.28	5.91	6.96	8.15	5.91	7.40	7.91	1.65	6.07	7.38
Bin 3 (AVLB)			4.86	5.54	7.22	4.86	6.42	6.79	3.27	5.23	8.41
Bin 4 (MTV)				4.17	6.10	4.11	5.47	6.71	5.96	1.98	8.48
Bin 5 (M985-10)					3.71	4.58	3.99	4.47	6.61	4.11	8.86
Bin 6 (M917)						6.73	2.33	2.83	7.98	5.99	9.82
Bin 7 (MTVM1095)							5.59	6.94	6.07	4.38	9.10
Bin 8 (M985M989)								3.26	7.28	5.50	9.55
Bin 9 (M911M747)									7.67	6.87	10.46
Bin 10 (M113A2)										6.14	7.32
Bin 11 (LAV25)											8.42
Bin 12 (Kawasaki ATV)											

Figure 83. Average NRMM Speed Differences and Standard Deviations for Terrain 13CW300A (mph).

Figure 83 shows the same terrain as Figure 80, except in this case the terrain is in the "Wet" condition. As can be seen, there is not a significant change in the results.

Average Prediction Delta (mph)

Bin 1 (M1A1)	7.19	11.28	11.13	13.91	17.60	11.13	16.08	19.64	8.29	9.21	9.39
Bin 2 (MLRS)		4.30	4.37	7.38	10.65	4.37	9.26	12.66	2.37	5.02	10.08
Bin 3 (AVLB)			2.64	5.65	6.98	2.64	5.27	8.37	3.49	6.19	13.87
Bin 4 (MTV)				4.20	7.99	3.50	6.79	10.04	3.72	2.52	12.18
Bin 5 (M985-10)					3.87	6.62	2.67	5.92	6.83	6.07	16.21
Bin 6 (M917)						7.27	2.81	2.46	9.61	9.34	20.00
Bin 7 (MTVM1095)							5.52	8.73	3.81	5.37	13.39
Bin 8 (M985M989)								3.99	8.34	8.14	18.47
Bin 9 (M911M747)									11.63	11.39	21.99
Bin 10 (M113A2)										4.13	11.23
Bin 11 (LAV25)											11.24
Bin 12 (Kawasaki ATV)											

Predicted Delta Standard Deviation

Bin 1 (M1A1)	7.03	7.03	7.56	11.81	12.97	7.56	11.19	11.43	7.29	10.65	5.23
Bin 2 (MLRS)		2.76	4.21	6.75	8.57	4.21	7.07	7.43	1.62	5.23	5.04
Bin 3 (AVLB)			4.09	4.57	7.32	4.09	6.03	6.39	3.58	5.25	6.04
Bin 4 (MTV)				4.67	5.84	4.34	4.73	5.81	5.25	3.34	4.73
Bin 5 (M985-10)					2.56	4.32	3.82	3.22	7.34	6.53	5.00
Bin 6 (M917)						7.31	2.45	2.73	9.47	7.81	6.31
Bin 7 (MTVM1095)							5.74	6.63	5.17	4.43	5.82
Bin 8 (M985M989)								2.23	8.06	6.37	6.24
Bin 9 (M911M747)									8.50	7.89	6.60
Bin 10 (M113A2)										6.01	5.59
Bin 11 (LAV25)											5.96
Bin 12 (Kawasaki ATV)											

Figure 84. Average NRMM Speed Differences and Standard Deviations for Terrain 8CS300A (mph).

Figure 84 presents results for a snow-covered terrain. Although the prediction deltas have grown slightly further apart, the results are similar to those depicted in the previous figures.

Average Prediction Delta (mph)

	Bin 2 (MLRS)	Bin 3 (AVLB)	Bin 4 (MTV)	Bin 5 (M985-10)	Bin 6 (M917)	Bin 7 (MTVM1095)	Bin 8 (M985M989)	Bin 9 (M911M747)	Bin 10 (M113A2)	Bin 11 (LAV25)	Bin 12 (Kawasaki ATV)
Bin 1 (M1A1)	4.81	10.64	10.71	13.54	18.82	10.71	15.90	21.50	4.53	5.15	8.55
Bin 2 (MLRS)		5.96	6.70	9.80	14.42	6.70	11.42	17.02	3.43	7.47	11.74
Bin 3 (AVLB)			3.41	7.79	9.05	3.41	6.40	11.32	6.45	11.75	17.51
Bin 4 (MTV)				5.90	11.06	4.29	9.00	14.12	6.75	6.61	14.82
Bin 5 (M985-10)					5.82	7.90	3.76	8.88	16.31	11.64	20.39
Bin 6 (M917)						8.86	3.41	3.06	10.49	17.27	25.75
Bin 7 (MTVM1095)							6.23	11.48	7.15	10.51	17.45
Bin 8 (M985M989)								5.60	13.03	15.21	22.75
Bin 9 (M911M747)									7.43	20.33	28.35
Bin 10 (M113A2)										6.86	11.74
Bin 11 (LAV25)											11.28

Predicted Delta Standard Deviation

	Bin 2 (MLRS)	Bin 3 (AVLB)	Bin 4 (MTV)	Bin 5 (M985-10)	Bin 6 (M917)	Bin 7 (MTVM1095)	Bin 8 (M985M989)	Bin 9 (M911M747)	Bin 10 (M113A2)	Bin 11 (LAV25)	Bin 12 (Kawasaki ATV)
Bin 1 (M1A1)	3.98	3.98	5.09	9.80	10.53	5.09	8.70	9.95	3.73	8.05	7.54
Bin 2 (MLRS)		2.58	4.36	8.12	8.97	4.36	7.21	8.18	2.17	7.01	7.26
Bin 3 (AVLB)			5.00	5.42	7.82	5.00	5.80	6.64	3.86	7.37	6.84
Bin 4 (MTV)				5.30	6.89	4.95	4.01	6.43	5.82	5.82	6.81
Bin 5 (M985-10)					3.18	4.52	4.47	4.32	9.45	10.37	5.34
Bin 6 (M917)						8.10	2.91	3.00	7.95	11.80	5.33
Bin 7 (MTVM1095)							5.57	7.79	4.82	5.43	8.32
Bin 8 (M985M989)								3.38	8.54	8.78	6.12
Bin 9 (M911M747)									7.07	11.30	6.07
Bin 10 (M113A2)										7.47	9.41
Bin 11 (LAV25)											10.31

Figure 85. Average NRMM Speed Differences and Standard Deviations for Terrain 4RD300A (mph).

Figure 85 presents results for a dry road terrain. In this example, the prediction deltas have increased again. This is because of the varying top speeds that vehicles can reach on roads. The LAV25 can reach a top speed of 62 mph while the MTV can only reach a top speed of 58 mph, therefore the increased prediction delta was expected.

As these figures have shown, for most situations there are modest to significant differences between ten of the twelve vehicle bins. This indicates that the binning methodology provides a distinction between vehicles of various mobility capabilities. The other two vehicles, LAV25 and M113A2, are very similar to the MTV and MLRS, respectively. It would appear based on the data examined that these vehicle bins are redundant and possibly not necessary for mobility speed predictions. In other words, sufficient results could be produced if the LAV25 were represented by the MTV's bin and the M113A2 by the MLRS's bin.

APPENDIX C – WORLD CLIMATE ZONES

APPENDIX C - WORLD CLIMATE ZONES

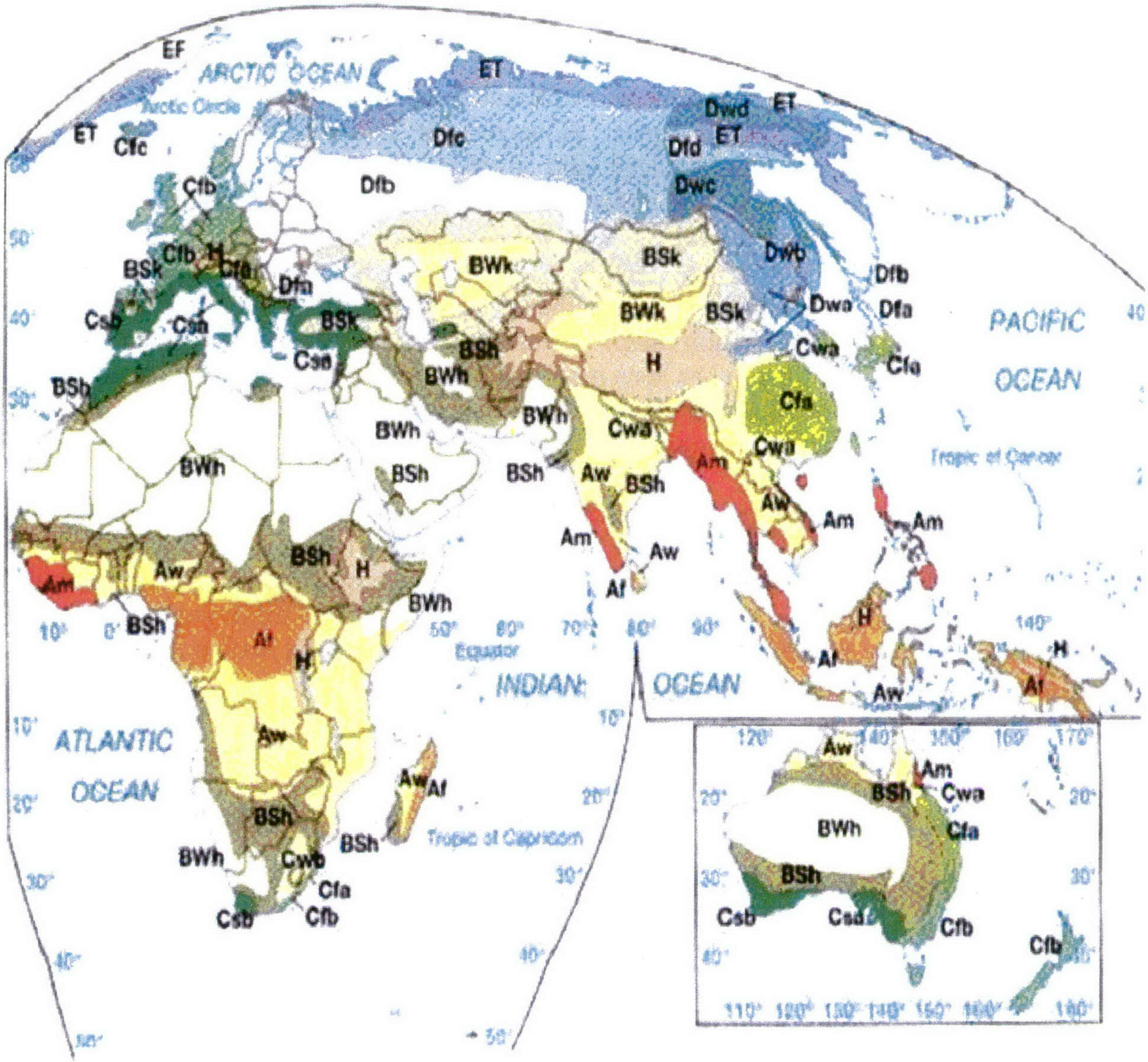
Various attempts have been made to classify the climates of the earth into climatic regions. One notable, yet ancient and misguided example is that of Aristotle's Temperate, Torrid, and Frigid Zones. However, the 20th century classification developed by German climatologist and amateur botanist Vladimir Köppen (1846-1940) continues to be the authoritative map of the world climates in use today.

Introduced in 1928 as a wall map co-authored with student Rudolph Geiger, the Köppen system of classification (map) was updated and modified by Köppen until his death. Since that time, it has been modified by several geographers. The most common modification of the Köppen system today is that of the late University of Wisconsin geographer Glen Trewartha (Ref. 6).

The STNDMob uses the Trewartha update to the Köppen system. Figure 86 depicts the eastern hemisphere climate zone and Figure 87 shows the western hemisphere climate zone. These maps should be useful to the User when attempting to match a simulation play box with the proper climatic zone. Table 29 provides a short description of the various zones and coding system. The last portion of this section describes the Köppen/Trewartha system in detail. See Section 2 of this discussion for Trewartha details.

The User should be aware that there are several versions of the Koppen/Trewartha available and care should be taken to assure that the classification system selected is in agreement with the STNDMob.

Another good global resource for selecting the proper climate zone can be found at: http://fp.arizona.edu/khirschboeck/climate/images/global.climate.map.med.jpg.



A TROPICAL HUMID CLIMATES

	Af	Tropical wet climate
	Am	Tropical monsoonal climate
	Aw	Tropical savanna climate

B DRY CLIMATES

	BWh	Subtropical desert
	BWk	Midlatitude desert
	BSh	Subtropical steppe
	BSk	Midlatitude steppe

D SEVERE MIDLATITUDE CLIMATES

	Dfa Dfb	Humid continental, no dry season
	Dwa Dwb	Humid continental, winter–dry
	Dfc Dfd	Subarctic, no dry season
	Dwc Dwd	Subarctic, winter–dry

E POLAR CLIMATES

	ET	Tundra
	EF	Ice cap

H HIGHLAND

	H	Cold climates due to elevation

C MILD MIDLATITUDE CLIMATES

	Cfa	Humid subtropical, no dry season
	Cwa Cwb	Humid subtropical, winter–dry
	Cfb Cfc	Marine west coast, no dry season
	Csa Csb	Mediterranean summer–dry

Figure 86. Köppen/Trewartha Climate Zone Map – Eastern Hemisphere (Ref 5).

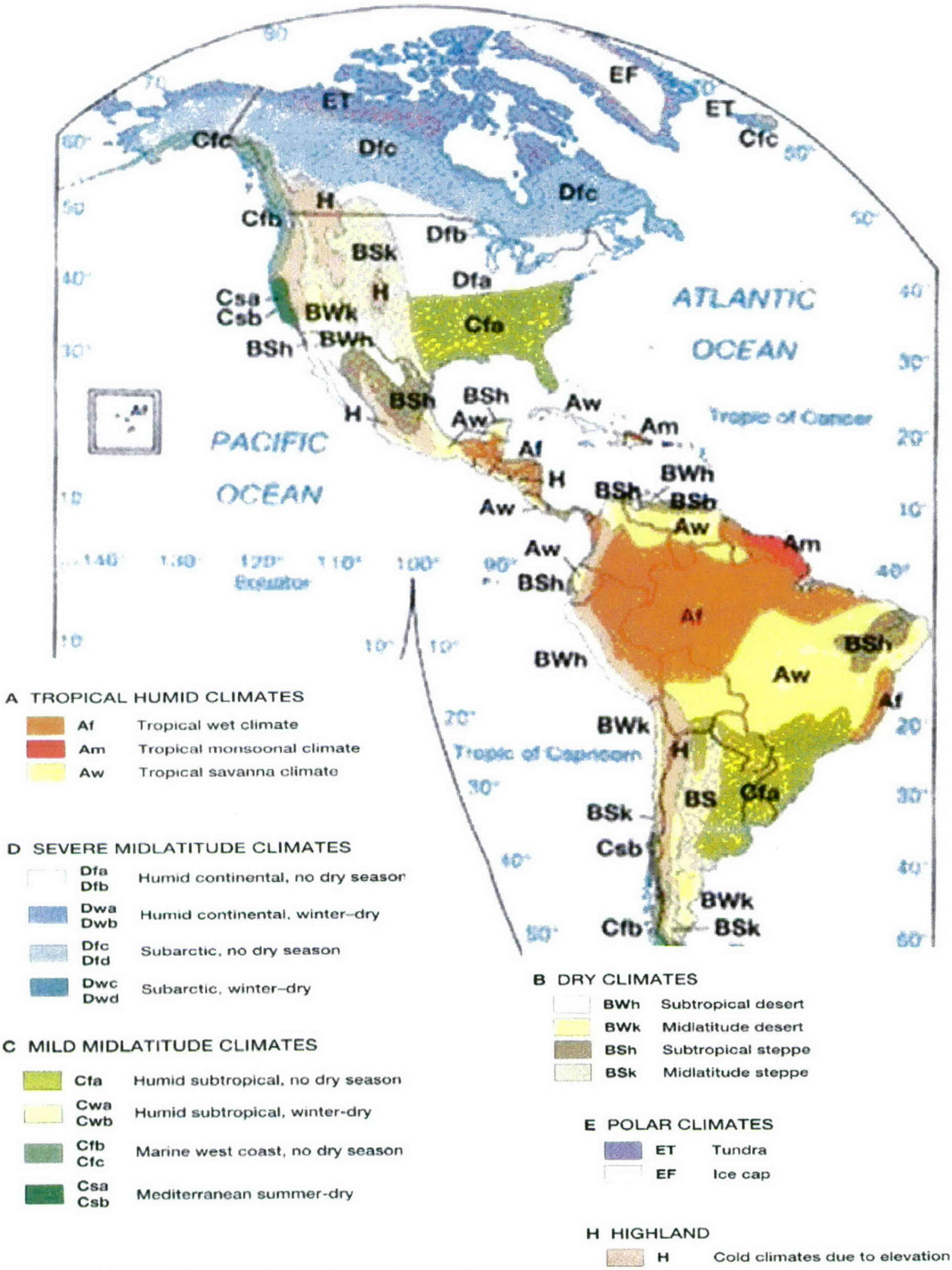


Figure 87. Köppen/Trewartha Climate Zone Map – Western Hemisphere (Ref. 13).

Table 29. Koppen/Trewartha Climate Chart (Ref. 7).

A	**Tropical**	Af	Tropical wet	No dry season
		Am	Tropical monsoonal	Short dry season; heavy monsoonal rains in other months
		Aw	Tropical savanna	Winter dry season
B	**Dry**	BWh	Subtropical desert	Low-latitude desert
		BSh	Subtropical steppe	Low-latitude dry
		BWk	Mid-latitude desert	Mid-latitude desert
		BSk	Mid-latitude steppe	Mid-latitude dry
C	**Humid Mesothermal (Mild Mid-Latitude)**	Csa	Mediterranean	Mild with dry, hot summer
		Csb	Mediterranean	Mild with dry, warm summer
		Cfa	Humid subtropical	Mild with no dry season, hot summer
		Cwa	Humid subtropical	Mild with dry winter, hot summer
		Cfb	Marine west coast	Mild with no dry season, warm summer
		Cfc	Marine west coast	Mild with no dry season, cool summer
D	**Humid Microthermal (Severe Mid-Latitude)**	Dfa	Humid continental	Humid with severe winter, no dry season, hot summer
		Dfb	Humid continental	Humid with severe winter, no dry season, warm summer
		Dwa	Humid continental	Humid with severe, dry winter, hot summer
		Dwb	Humid continental	Humid with severe, dry winter, warm summer
		Dfc	Subarctic	Severe winter, no dry season, cool summer
		Dfd	Subarctic	Severe, very cold winter, no dry season, cool summer
		Dwc	Subarctic	Severe, dry winter, cool summer
		Dwd	Subarctic	Severe, very cold and dry winter, cool summer
E	**Polar**	ET	Tundra	Polar tundra, no true summer
		EF	Ice Cap	Perennial ice
H	**Highland**	H	High Altitude	Altitude plays a role in determining climate classification

NOTE: The remainder of Appendix C is sourced from Reference 8.

1.0 Köppen Climate Classification (Ref. 8)

The **Köppen climate classification** is one of the most widely used climate classification systems. It was developed by Vladimir Köppen, a German climatologist, around 1900 (with several further modifications by himself, notably in 1918 and 1936). It is based on the concept that native vegetation is the best expression of climate, thus climate zone boundaries have been selected with vegetation distribution in mind. It combines average annual and monthly temperatures and precipitation, and the seasonality of precipitation.

The Scheme

Köppen climate classification scheme divides the climates into five main groups and several types and subtypes. Each particular climate type is represented by a 2 to 4 letter symbol:

GROUP A: Tropical/Megathermal climates

Tropical climates (see tropics) are characterized by constant high temperature - all twelve months of the year have average temperatures of 18°C (64.4°F) or higher. They are subdivided as follows:

- **Tropical rain forest climate** (*Af*): All twelve months have average precipitation of at least 60 mm (2.36 inches). These climates, usually occurring within 5° latitude of the equator, are dominated by the Doldrums Low Pressure System all year round, and thus have no real seasons.
  Examples: Singapore
  Belém, Brazil.
  Some of the places that have this climate are indeed uniformly and monotonously wet throughout the year (e.g., Andagoya, Colombia), but in many cases the period of higher sun and longer days is distinctly wettest (as at Palembang, Indonesia) or the time of lower sun and shorter days may have more rain (as at Sitiawan, Malaysia).
  A few places with this climate are found at the outer edge of the tropics, almost exclusively in the Southern Hemisphere; one example is Santos, Brazil.
- **Tropical monsoon climate** (*Am*): This type of climate, most common in southern Asia and West Africa, results from the monsoon winds which change direction according to the seasons. This climate has a driest month (which nearly always occurs at or soon after the "winter" solstice for that side of the equator) with rainfall less than 60 mm, but more than (100 - [total annual precipitation {mm}/25]):
  Examples: Conakry, Guinea
  Chittagong, Bangladesh.
  There is also another scenario under which some places fit into this category; this is referred to as the *trade-wind littoral* climate because easterly winds bring enough precipitation during the "winter" months to prevent the climate from becoming a tropical wet-and-dry climate. Jakarta, Indonesia and Miami, Florida are included among these locations.

- **Tropical wet and dry or savanna climate** (*Aw*): These climates have a pronounced dry season, with the driest month having precipitation less than 60 mm and also less than (100 - [total annual precipitation {mm}/25]):
  Examples: Bangalore, India
  Veracruz, Mexico
  Townsville, Australia.
  Most places that have this climate are found at the outer margins of the tropical zone, but occasionally an inner-tropical location (e.g., San Marcos, Colombia) also qualifies. Sometimes *As* is used in place of *Aw* if the dry season occurs during the time of higher sun and longer days. This is the case in parts of Hawaii (Honolulu), East Africa (Mombasa, Kenya) and Sri Lanka (Trincomalee), for instance. In most places that have tropical wet and dry climates, however, the dry season occurs during the time of lower sun and shorter days.

GROUP B: Dry (Arid and semiarid) climates

These climates are characterized by the fact that precipitation is less than potential evaporation and transpiration. The threshold is determined as follows:

- To find the precipitation threshold (in millimeters), multiply the average annual temperature in °C by 20, then add 280 if 70 percent or more of the total precipitation is in the high-sun half of the year (April through September in the Northern Hemisphere, or October through March in the Southern), or 140 if 30 percent-70 percent of the total precipitation is received during the applicable period, or 0 if less than 30 percent of the total precipitation is so received.
- If the annual precipitation is less than half the threshold for Group B, it is classified as *BW* (desert climate) - if it is less than the threshold but more than half the threshold, it is classified as *BS* (steppe climate).
- A third letter can be included to indicate temperature. Originally, *h* signified low latitude climate (average annual temperature above 18°C) while *k* signified middle latitude climate (average annual temperature below 18°C), but the more common practice today (especially in the United States) is to use *h* to mean that the coldest month has an average temperature that is above 0°C (32°F), with *k* denoting that at least one month averages below 0°C.
- Examples: Yuma, Arizona (*BWh*)
  Turpan, China (*BWk*)
  Cobar, Australia (*BSh*)
  Medicine Hat, Alberta (*BSk*).
  Some desert areas, situated along the west coasts of continents at tropical or near-tropical locations, are characterized by cooler temperatures than encountered elsewhere at comparable latitudes (due to the nearby presence of cold ocean currents) and frequent fog and low clouds, despite the fact that these places rank among the driest on earth in terms of actual precipitation received. This climate is sometimes labelled *BWn* and examples can be found at Lima, Peru and Walvis Bay, Namibia.
- On occasion, a fourth letter is added to indicate if either the winter or summer is "wetter" than the other half of the year. To qualify, the wettest month must have at least 60 mm of

average precipitation if all twelve months are above 18°C, or 30 mm (1.18 inches) if not; plus at least 70 percent of the total precipitation must be in the same half of the year as the wettest month - but the letter used indicates when the *dry* season occurs, not the "wet" one. This would result in Khartoum, Sudan being reckoned as *BWhw*, Niamey, Niger as *BShw*, El Arish, Egypt as *BWhs*, Asbi'ah, Libya as *BShs*, Umnugobi, Mongolia as *BWkw*, and Xining, China as *BSkw* (*BWks* and *BSks* do not exist). If the standards for neither *w* nor *s* are met, no fourth letter is added.

GROUP C: Temperate/mesothermal climates

These climates have an average temperature above 10°C (50°F) in their warmest months, and a coldest month average between -3°C and 18°C. (Some climatologists, particularly in the United States, prefer to observe 0°C rather than -3°C in the coldest month as the boundary between this group and Group D; this is done to prevent certain headland locations in New England - principally Cape Cod - and such nearby islands as Nantucket and Martha's Vineyard, from fitting into the Maritime Temperate category noted below; this category is alternately known as the *Marine West Coast* climate, and eliminating the aforementioned locations confines it exclusively to places found along the western margins of the continents, at least in the Northern Hemisphere).

- The second letter indicates the precipitation pattern - *w* indicates dry winters (driest winter month average precipitation less than one-tenth wettest summer month average precipitation; one variation also requires that the driest winter month have less than 30 mm average precipitation), *s* inidicates dry summers (driest summer month less than 30 mm average precipitation and less than one-third wettest winter month precipitation) and *f* means significant precipitation in all seasons (neither above mentioned set of conditions fulfilled).
- The third letter indicates the degree of summer heat - *a* indicates warmest month average temperature above 22°C (71.6°F), *b* indicates warmest month average temperature below 22°C, with at least 4 months averaging above 10°C, while *c* means 3 or fewer months with mean temperatures above 10°C.
- The order of these two letters is sometimes reversed, especially by climatologists in the United States.
- Group C climates are subdivided as follows:
  - **Mediterranean climates** (*Csa*, *Csb*): These climates usually occur on the western sides of continents between the latitudes of 30° and 45°. These climates are in the polar front region in winter, and thus have moderate temperatures and changeable weather. Summers are hot and dry, due to the domination of the subtropical high pressure systems, except in the immediate coastal areas, where summers are cooler due to the nearby presence of cold ocean currents.
    Examples: Palermo, Sicily (*Csa*)
    Gaziantep, Turkey (*Csa*)
    Santiago, Chile (*Csb*)
    Portland, Oregon (*Csb*).
  - **Humid Subtropical climates** (*Cfa*, *Cwa*): These climates usually occur in the interiors of continents, or on their east coasts, between the latitudes of 25° and

40°. Unlike the Mediterranean climates, the summers are humid due to unstable tropical air masses, or onshore Trade Winds. In eastern Asia, winters can be dry (and colder than other places at a corresponding latitude) because of the Siberian high pressure system, and summers very wet due to monsoonal influence.
Examples: Houston, Texas (*Cfa - uniform precipitation distribution*)
Brisbane, Australia (*Cfa - summer wetter than winter*)
Yalta, Ukraine (*Cfa - summer drier than winter*)
Luodian, China (*Cwa*).

  - **Maritime Temperate climates** (*Cfb*, *Cwb*): *Cfb* climates usually occur on the western sides of continents between the latitudes of 45° and 55°; they are typically situated immediately poleward of the Mediterranean climates, although in Australia this climate is found immediately poleward of the Humid Subtropical climate, and at a somewhat lower latitude. These climates are dominated all year round by the polar front, leading to changeable, often overcast weather. Summers are cool due to cloud cover, but winters are milder than other climates in similar latitudes.
    Examples: Limoges, France (*uniform precipitation distribution*)
    Langebaanweg, South Africa (*summer wetter than winter*)
    Prince Rupert, British Columbia (*summer drier than winter*).
    Cfb climates are also encountered at high elevations in certain tropical areas, where the climate would be that of a tropical rain forest if not for the altitude. Bogotá, Colombia is perhaps the best example.
    Cwb is found only at higher altitudes, without which the climate would be tropical wet and dry; examples include Addis Ababa, Ethiopia and Mexico City.
  - **Maritime Subarctic climates** (*Cfc*): These climates occur poleward of the Maritime Temperate climates, and are confined either to narrow coastal strips on the western poleward margins of the continents, or, especially in the Northern Hemisphere, to islands off such coasts.
    Examples: Punta Arenas, Chile (*uniform precipitation distribution*)
    Monte Dinero, Argentina (*summer wetter than winter*)
    Torshavn, Faroe Islands (*summer drier than winter*).

GROUP D: Continental/microthermal climate

These climates have an average temperature above 10°C in their warmest months, and a coldest month average below -3°C (or 0°C in some versions). These usually occur in the interiors of continents, or on their east coasts, north of 40° North latitude. Group D climates do not exist at all in the Southern hemisphere due to the smaller land masses here.

- The second and third letters are used as for Group C climates, while a third letter of *d* indicates 3 or fewer months with mean temperatures above 10°C *and* a coldest month temperature below -38°C (-36.4°F).
- Group D climates are subdivided as follows:
  - **Hot Summer Continental climates** (*Dfa*, *Dwa*, *Dsa*) - *Dfa* climates usually occur in the forties latitudes, and in eastern Asia *Dwa* climates extend further south due to the influence of the Siberian high pressure system, which also causes

winters here to be dry, and summers can be very wet because of monsoon circulation.
Examples: Lowell, Massachusetts (*Dfa - uniform precipitation distribution*)
Peoria, Illinois (*Dfa - summer wetter than winter*)
Santaquin, Utah (*Dfa - summer drier than winter*)
Beijing, China (*Dwa*).
Dsa exists only at higher elevations adjacent to areas with Mediterranean climates, such as Cambridge, Idaho and Saqqez in Iranian Kurdistan.

- **Warm Summer Continental climates** (*Dfb*, *Dwb*, *Dsb*) - *Dfb* and *Dwb* climates are immediately north of Hot Summer Continental climates, and also in central and eastern Europe, between the Maritime Temperate and Continental Subarctic climates.
Examples: Moncton, New Brunswick (*Dfb - uniform precipitation distribution*)
Minsk, Belarus (*Dfb - summer wetter than winter*)
Revelstoke, British Columbia (*Dfb - summer drier than winter*)
Rudnaya Pristan, Russia (*Dwb*).
Dsb arises from the same scenario as *Dsa*, but at even higher altitudes, and chiefly in North America since here the Mediterranean climates extend further poleward than in Eurasia; Mazama, Washington is one such location.
- **Continental Subarctic or Taiga climates** (*Dfc*, *Dwc*, *Dsc*) - *Dfc* and *Dwc* climates occur poleward of the other Group D climates, mostly north of 50° North latitude.
Examples: Sept-Iles, Quebec (*Dfc - uniform precipitation distribution*)
Anchorage, Alaska (*Dfc - summer wetter than winter*)
Mount Robson, British Columbia (*Dfc - summer drier than winter*)
Irkutsk, Russia (*Dwc*).
Dsc, like *Dsa* and *Dsb*, is confined exclusively to highland locations near areas that have Mediterranean climates, and is the rarest of the three as a still higher altitude is needed to produce this climate. Example: Galena Summit, Idaho.
- **Continental Subarctic climates with extremely severe winters** (*Dfd*, *Dwd*): These climates occur only in eastern Siberia. The names of some of the places that have this climate - most notably Verkhoyansk and Oymyakon - have become veritable synonyms for extreme, severe winter cold.

GROUP E: Polar climates

These climates are characterized by average temperatures below 10°C in all twelve months of the year:

- **Tundra climate** (*ET*): Warmest month has an average temperature between 0°C and 10°C. These climates occur on the northern edges of the North American and Eurasian landmasses, and on nearby islands; they also exist along the outer fringes of Antarctica (especially the Palmer Peninsula) and on nearby islands.
Examples: Iqaluit, Nunavut
Provideniya, Russia
Deception Island, Antarctica.

ET is also found at high elevations outside the polar regions, above the timber line - as at Mount Washington, New Hampshire.

- **Ice Cap climate** (*EF*): All twelve months have average temperatures below 0°C. This climate is dominant in Antarctica (e.g., Scott Base) and in inner Greenland (e.g., Eismitte).
- Occasionally, a third, lower-case letter is added to *ET* climates if either the summer or winter is clearly drier than the other half of the year; thus Qikiqtaruk, or Herschel Island, off the coast of Canada's Yukon Territory, becomes *ETw*, with Pic du Midi de Bigorre in the French Pyrenees acquiring an *ETs* designation. If the precipitation is more or less evenly spread throughout the year, *ETf* may be used, such as for Hebron, Labrador. When the option to include this letter is exercised, the same standards that are used for Groups C and D apply, with the additional requirement that the wettest month must have an average of at least 30 mm precipitation (Group E climates can be as dry or even drier than Group B climates based on actual precipitation received, but their rate of evaporation is much lower). Seasonal precipitation letters are almost never attached to *EF* climates, mainly due to the difficulty in distinguishing between falling and blowing snow, as snow is the sole source of moisture in these climates.

2.0 Trewartha Climate Classification Scheme

The Trewartha climate classification scheme is a modified version of the Köppen system. It attempts to redefine the broad climatic groups in such a way as to be closer to vegetational zoning.

- **Group A:** This the tropical climate group, defined the same as in Köppen's scheme (i.e., all 12 months average 18°C or above). Climates with no more than 2 dry months (defined as having less than 60mm average precipitation, same as per Köppen) are classified *Ar* (instead of Köppen's *Af*), while others are classified *Aw* if the dry season is at the time of low sun/short days or *As* if the dry season is at the time of high sun/long days. There was no specific monsoon climate identifier in the original scheme, but *Am* was added later, with the same parameters as Köppen's (except that at least three months, rather than one, must have less than 60mm average precipitation).
- **Group B:** *BW* and *BS* mean the same as in the Köppen scheme, with the Köppen *BWn* climate sometimes being designated *BM* (the *M* standing for "marine"). However, a different formula is used to quantify the aridity threshold: 10 X (T - 10) + 3P, with T equaling the mean annual temperature in degrees Celsius and P denoting the percentage of total precipitation received in the six high-sun months (April through September in the Northern Hemisphere and October through March in the Southern). If the precipitation for a given location is less than the above formula, its climate is said to be that of a desert (*BW*); if it is equal to or greater than the above formula but less than twice that amount, the climate is classified as steppe (*BS*); and if the precipitation is more than double the value of the formula the climate is not in Group B. Unlike in Köppen's scheme, no thermal subsets exist within this group in Trewartha's, unless the Universal Thermal Scale (see below) is used.
- **Group C:** In the Trewartha scheme this category encompasses subtropical climates only (8 or more months above 10°C). *Cs* and *Cw* have the same meanings as they do in

Köppen's scheme, but the subtropical climate with no distinct dry season is designated *Cr* instead of Köppen's *Cf* (and for *Cs* the average annual precipitation must be less than 890mm [35 inches] in addition to the driest summer month having less than 30mm precipitation and being less than one-third as wet as the wettest winter month).

- **Group D:** This group represents temperate climates (4 to 7 months above 10°C). Maritime temperate climates (most of Köppen's *Cfb* and *Cwb* climates, though some of these would fit into Trewartha's *Cr* and *Cw,* respectively) are denoted *DO* in the Trewartha classification (although some places near the east coasts of both North America and Asia actually qualify as *DO* climates in Trewartha's scheme when they fit into *Cfa/Cwa* rather than *Cfb/Cwb* in Köppen's), while continental climates are represented as *DCa* (Köppen *Dfa*, *Dwa*, *Dsa*) and *DCb* (Köppen *Dfb*, *Dwb*, *Dsb*). For the continental climates, sometimes the third letter (*a* or *b*) is omitted and *DC* is simply used instead, and occasionally a precipitational seasonality letter is added to both the maritime and continental climates (*r*, *w*, or *s*, as applicable). The dividing point between the maritime and continental climates is 0°C in the coldest month, rather than the Köppen value of -3°C (as noted in the section on the Köppen scheme, however, some climatologists - particularly in the United States - now observe 0°C in the coldest month as the equatorward limit of the continental climates in that scheme as well).
- **Group E:** This represents subarctic climates, defined the same as in Köppen's scheme (1 to 3 months with average temperatures of 10°C or above; Köppen *Cfc*, *Dfc*, *Dwc*, *Dsc*, *Dfd*, *Dwd*). In the original scheme, this group was not further divided; later, the designations *EO* and *EC* were created, with *EO* (maritime subarctic) signifying that the coldest month averages above -10°C, while *EC* (continental subartctic or "boreal") means that at least one month has an average temperature of -10°C or below. As in Group D, a third letter can be added to indicate seasonality of precipitation. There is no separate counterpart to the Köppen *Dfd/Dwd* climate in Trewartha's scheme.
- **Group F:** This is the polar climate group, split into *FT* (Köppen *ET*) and *FI* (Köppen *EF*).
- **Group H:** Highland climates, in which altitude plays a role in determining climate classification. Specifically, this would apply if correcting the average temperature of each month to a sea-level value using the formula of adding 5.6°C for each 1,000 meters of elevation would result in the climate fitting into a different thermal group than that into which the actual monthly temperatures place it. Sometimes *G* is used instead of *H* if the above is true and the altitude is 500 meters or higher but lower than 2,500 meters; but the *G* or *H* is placed in front of the applicable thermal letter rather than replacing it - and the second letter used reflects the *corrected* monthly temperatures, not the actual monthly temperatures.
- **Universal Thermal Scale:** An option exists to include information on both the warmest and coldest months for every climate by adding a third and fourth letter, respectively. The letters used conform to the following scale:
  i - severely hot: Mean monthly temperature 35°C or higher
  h - very hot: 28 to 34.9°C
  a - hot: 23 to 27.9&deg:C
  b - warm: 18 to 22.9&deg:C
  l - mild: 10 to 17.9°C
  k - cool: 0.1 to 9.9°C

o - cold: -9.9 to 0°C
c - very cold: -24.9 to -10°C
d - severely cold: -39.9 to -25°C
e - excessively cold: -40°C or below.
Examples of the resulting designations include *Afaa* for Kuala Lumpur, Malaysia, *BWhl* for Aswan, Egypt, *Crhk* for Dallas, Texas, *DOlk* for London, England, *EClc* for Arkhangelsk, Russia, and *FTkd* for Barrow, Alaska.

3.0 Criticisms of the Köppen Scheme

Some climatologists have argued that Köppen's system could be improved upon. One of the most frequently-raised objections concerns the temperate Group C category, regarded by many as overbroad (it includes both Tampa, Florida and Cape May, New Jersey, for example). In *Applied Climatology* (first edition published in 1966), John Griffiths proposed a new *subtropical* zone, encompassing those areas with a coldest month of between 6°C (42.8°F) and 18°C, effectively subdividing Group C into two nearly equal parts (his scheme assigns the letter *B* to the new zone, and identifies dry climates with an additional letter immediately following the temperature-based letter).

Another point of contention involves the dry *B* climates; the argument here is that their separation by Köppen into only two thermal subsets is inadequate. Those who hold this view (including Griffiths) have suggested that the dry climates be placed on the same temperature continuum as other climates, with the thermal letter being followed by an additional capital letter - *S* for steppe or *W* (or *D*) for desert - as applicable.

A third idea is to create a *maritime polar* or *EM* zone within Group E to separate relatively mild marine locations (such as Ushuaia, Argentina and the outer Aleutian Islands) from the colder, continental tundra climates. Specific proposals vary; some advocate setting a coldest-month parameter, such as -7°C (19.4°F), while others support assigning the new designation to areas with an average annual temperature of above 0°C.

The accuracy of the 10°C warmest-month line as the start of the polar climates has also been questioned; Otto Nordenskiöld, for example, devised an alternate formula: $W = 9 - 0.1\ C$, with W representing the average temperature of the warmest month and C that of the coldest month, both in degrees Celsius (for instance, if the coldest month averaged -20° C, a warmest-month average of 11°C or higher would be necessary to prevent the climate from being polar). This boundary does appear to more closely follow the tree line, or the latitude poleward of which trees cannot grow, than the 10°C warmest-month isotherm; the former tends to run poleward of the latter near the western margins of the continents, but at a lower latitide in the landmass interiors, the two lines crossing at or near the east coasts of both Asia and North America.

APPENDIX D – VISIBILITY / OBSTACLE (VISOBS) TABLE

Table 30. Visibility and Visibility – Obstacle Combinations (VISOBS) (Ref. 1).

Visibility (road/trail)	Visibility Distance (ft)	Visibility Distance Definitions NOTE: Visibility only factored for roads and trails / Obstacles not considered
1	300	Virtually unlimited visibility, distant spacing of vehicles, no precipitation, day-time lighting, headlights at night, no obscurants, good contrast
2	100	Somewhat limited visibility, distant spacing of vehicles, light precipitation, day-time lighting, headlights at night, obscurants or blackout w/vision enhancement devices, fair contrast
3	50	Limited visibility, close spacing of vehicles, heavy precipitation/fog, low solar/lunar illumination, heavy obscurants w/vision enhancement devices, poor contrast
4	25	Very limited visibility, close spacing of vehicles, no solar/lunar illumination, heavy obscurants and/or blackout w/no enhanced vision devices, very poor contrast

Visibility - Obstacle Combinations (i.e., VISOBS) (cross-country)	Visibility Distance (ft)	Obstacle Spacing (ft)	Obstacle Spacing Definitions NOTE: Visibility and obstacles are both considered for cross-country. Refer to visibility distance definitions above in association with the obstacle spacing definitions
1	300	150	Uncluttered
2	100	150	"
3	50	150	"
4	25	150	"
5	300	30	Cluttered due to urban or industrial area damage, concentration of damaged vehicles, cratering, rubble, rock outcrops, some vegetation
6	100	30	"
7	50	30	"
8	25	30	"
9	300	25	same as above
10	100	25	"
11	50	25	"
12	25	25	"
13	300	20	*Severely* cluttered due to heavy urban or industrial area damage, *dense* concentration of damaged vehicles, cratering, rubble, rock outcrops, dense vegetation
14	100	20	"
15	50	20	"
16	25	20	"

APPENDIX E – NRMM SCENARIO FILE USED FOR THE CREATION OF STNDMOB SPEED TABLES

APPENDIX E – NRMM SCENARIO FILE USED FOR THE CREATION OF STNDMob SPEED TABLES

STNDMob Fidelity 1 and 2 predictions are extracted from speed tables that are based on NRMM results. The NRMM scenario file attached at the bottom of this section was used to produce those NRMM results.

Please review the NATO Reference Mobility Model Edition II, NRMM II Users Guide (Ref. 9) and NATO Reference Mobility Model Edition II, NRMM II User's Guide Addendum Model Changes and Updates through Version 2.6.9 (Ref. 10) for an in-depth discussion of the variables used within the NRMM scenario file and questions regarding NRMM in general. The next paragraphs define some higher level NRMM environmental conditions that may be found within the NRMM scenario file.

Soil Moisture Season Conditions

These descriptions are based on the report titled Methodology for the Development of Inference Algorithms for Worldwide Application of Interim Terrain Data to the NATO Reference Mobility Model (Ref. 2).

NRMM can consider the following soil moisture season conditions (i.e., ISEASN) within the scenario file:

- **Dry:** The dry condition describes the lowest soil moisture and associated soil strength found during the driest consecutive 30-day period of an average rainfall year.
- **Average:** The average condition describes soil moisture and associated soil strength found during the average 180-day period for an average rainfall year.
- **Wet:** The wet condition describes soil moisture and associated soil strength found during the wettest consecutive 30-day period for an average rainfall year.
- **Wet-Wet**: The wet-wet condition describes the highest soil moisture and associated soil strength found during the wettest consecutive 10-day period for a year having 150 percent of average rainfall.

NOTE: Only the Dry and Wet conditions are represented within the current STNDMob speed tables.

Surface Slipperiness Conditions (Ref. 10)

NRMM can consider the following soil surface slipperiness conditions (i.e., NSLIP) within the scenario file:

- **Normal:** Surface is dry and non-slippery
- **Slippery:** Surface is wet and slippery

NOTE: Normal and Slippery conditions are both represented within the STNDMob speed tables. Only the soft-soil sub-models for fine-grained and coarse grained soils are affected by slipperiness; slipperiness has no affect with regards to snow conditions.

Scenario Snow Conditions (Ref. 10)

NRMM can consider the following snow condition attributes within the scenario file:

- Depth of snow (i.e., ZSNOW)
- Density of snow (i.e., GAMMA)
- Depth of frozen ground (i.e., ZFREEZ)
- Depth of thawing ground (i.e., ZTHAW)
- Scenario snow model enable (i.e., ISNOW)

The snow conditions selected for each climate zone were based on Estimated Snow Parameters for Vehicle Mobility Modeling in Korea, Germany and Interior Alaska (Ref. 11).

Road/Trail/Cross-Country Definitions (Ref. 12)

Roads

- **Super-Highways**: Multi-lane, high speed, high density, limited access roads such as Autobahns and Interstate highways. Surface roughness values ranges from 0.1 inch RMS to 0.3 inch RMS.

- **Primary Roads**: Two or more lanes, all-weather, maintained, hard surface roads with good driving visibility used for heavy and high density traffic. These roads have lanes with a minimum width of 2.7 m (9 ft.) and the legal maximum GVW/gross combined weight for the country or state is assured for all bridges. Surface roughness values ranges from 0.1 inch RMS to 0.3 inch RMS.

- **Secondary Roads**: Two lane, all-weather, occasionally maintained, hard or loose surface (paved, crushed rock, gravel) roads intended for medium-weight, low density traffic. These roads have lanes with a minimum width of 2.4 m (8 ft.) and no guarantee that the legal maximum GVW/gross combined weight for the country or state is assured for all bridges. Surface roughness values ranges from 0.1 inch RMS to 0.6 inch RMS.

Trails: One lane, dry weather, unimproved, seldom maintained, loose surface roads intended for low-density traffic. Trails have a minimum lane width of 2.4 m (8 ft.), no large obstacles (boulders, stumps, logs…) and no bridging. Surface roughness values ranges from 0.1 inch RMS to 2.8 inch RMS.

Cross-Country (Off-Road): Vehicle operations over virgin terrain which has no previous traffic (Cross-Country), and over combat and pioneer trails.

NRMM Scenario File Used for the Creation of STNDMob Speed Tables

NOTE: All text on a single line following the "!" character is for comment only and, thus, has no impact upon the NRMM results.

```
DRY-NORMAL
Dry-Normal,October,
 $SCENAR
! NTRAV=3,                                  !predicts for up,level,down
 ISEASN=1, MONTH=10,                        !soil moisture season=dry, 4th quarter
 LAC=1,                                     !ride level index
 SAFE=0.0,                                  !SAFE=1.0 in the most conservative to
! AASHTO criteria. SAFE=0.0 is the least conservative.
 ISAND= 0,
 NSLIP=0, ISURF=1, ISNOW=0                  !surface not slippery and dry
 NOPP=0,                                    !tire deflection
 COEFHD=1.0,
 RDFOG=300., REACT=.75, DCLMAX=2.0, SFTYPC=90.0,
 VBRAKE= 2.0, VISMNV= 2.0, VLIM= 100.0, VWALK=  4.0,
 $END
!
WET-SLIPRY
Wet-Slippery,June,
 $SCENAR
 ISEASN=3, Month=6,                          !soil moisture=wet, 2nd quarter
 LAC=1,
 SAFE=1.0,
 ISAND= 0,
 NSLIP= 1, ISURF=2, ISNOW=0                  !surface=slippery and wet
 NOPP= 0,
 COEFHD=1.0,
 RDFOG=300., REACT=.75, DCLMAX=2.0, SFTYPC=90.0,
 VBRAKE= 2.0, VISMNV= 2.0, VLIM= 80.0, VWALK=  4.0,
 $END
!
SNOW-ROADS                      !2/03/03  use for hi/prim/sec for all regions
Dry,Snow,All
 $SCENAR   !model controls
 NTRAV=0,                                  !selects 2 for roads, 3 for cc 9/29/00
 LAC=1,                                    !ride level index
 SAFE=1.0,                                 !AASHO limits - off 9/28/00
 NOPP=0,                                   !tire deflection scenario variables
 ISEASN=1, NSLIP=0, ISURF=1,               !5/30/01
 ISNOW= 1, ISAND=0,                        !snow (CRREL), no sand
 GAMMA=0.1, ZSNOW=4.0,                     !fresh snow, maintenance occurs9/01/99
 ZFREEZ=30, ZTHAW=0,
 MONTH= 1,                                 !vis season = 1st quarter
 RDFOG=300.0,                               !max RDA driver variables
 COEFHD=1.0,                               !max side slope
 REACT=.75,    DCLMAX=2.0,  SFTYPC=90.0,!braking
 VBRAKE= 2.0, VISMNV= 2.0,                 !min vis-limited speeds
 VWALK=  4.0,                              !min veg-override speed
 VLIM= 100.0,                              !max on-road speed
 $END
!
SNOW-3TRCC                  !2/03/03  Region 3, trails & cc
```

```
Dry,Snow,Region3
 $SCENAR   !model controls
 NTRAV=0,                                   !selects 2 for roads, 3 for cc 9/29/00
 LAC=1,                                     !ride level index
 SAFE=1.0,                                  !AASHO limits - off            9/28/00
 NOPP=0,                                    !tire deflection scenario variables
 ISEASN=1, NSLIP=0, ISURF=1,                !5/30/01
 ISNOW= 1, ISAND=0,                         !snow (CRREL), no sand
 GAMMA=0.275, ZSNOW=9.8,                    !2/03/03  central Germany averages
 ZFREEZ=30, ZTHAW=0,
 MONTH= 1,                                  !vis season = 1st quarter
 RDFOG=300.0,                                !max RDA driver variables
 COEFHD=1.0,                                !max side slope
 REACT=.75,   DCLMAX=2.0,   SFTYPC=90.0,!braking
 VBRAKE= 2.0, VISMNV= 2.0,                  !min vis-limited speeds
 VWALK=  4.0,                               !min veg-override speed
 VLIM= 100.0,                               !max on-road speed
 $END
!
```
SNOW-4TRCC `!2/03/03  Region 4, trails & cc`
```
Dry,Snow,Region4
 $SCENAR    !model controls
 NTRAV=0,                                   !selects 2 for roads, 3 for cc 9/29/00
 LAC=1,                                     !ride level index
 SAFE=1.0,                                  !AASHO limits - off            9/28/00
 NOPP=0,                                    !tire deflection scenario variables
 ISEASN=1, NSLIP=0, ISURF=1,                !5/30/01
 ISNOW= 1, ISAND=0,                         !snow (CRREL), no sand
 GAMMA=0.275, ZSNOW=7.1,                    !2/03/03  Korea averages
 ZFREEZ=30, ZTHAW=0,
 MONTH= 1,                                  !vis season = 1st quarter
 RDFOG=300.0,                                !max RDA driver variables
 COEFHD=1.0,                                !max side slope
 REACT=.75,   DCLMAX=2.0,   SFTYPC=90.0,!braking
 VBRAKE= 2.0, VISMNV= 2.0,                  !min vis-limited speeds
 VWALK=  4.0,                               !min veg-override speed
 VLIM= 100.0,                               !max on-road speed
 $END
!
```
SNOW-5TRCC `!2/03/03  Region 5, trails & cc`
```
Dry,Snow,Region5
 $SCENAR    !model controls
 NTRAV=0,                                   !selects 2 for roads, 3 for cc 9/29/00
 LAC=1,                                     !ride level index
 SAFE=1.0,                                  !AASHO limits - off            9/28/00
 NOPP=0,                                    !tire deflection  scenario variables
 ISEASN=1, NSLIP=0, ISURF=1,                !5/30/01
 ISNOW= 1, ISAND=0,                         !snow (CRREL), no sand
 GAMMA=0.23, ZSNOW=19.7,                    !2/03/03  Alaska averages
 ZFREEZ=30, ZTHAW=0,
 MONTH= 1,                                  !vis season = 1st quarter
 RDFOG=300.0,                                !max RDA driver variables
 COEFHD=1.0,                                !max side slope
 REACT=.75,   DCLMAX=2.0,   SFTYPC=90.0,!braking
 VBRAKE= 2.0, VISMNV= 2.0,                  !min vis-limited speeds
 VWALK=  4.0,                               !min veg-override speed
 VLIM= 100.0,                               !max on-road speed
```

```
 $END
!
SNOW-6TRCC                !2/03/03  Region 6, trails & cc
Dry,Snow,Region6
 $SCENAR   !model controls
 NTRAV=0,                                       !selects 2 for roads, 3 for cc 9/29/00
 LAC=1,                                         !ride level index
 SAFE=1.0,                                      !AASHO limits - off          9/28/00
 NOPP=0,                                        !tire deflection scenario variables
 ISEASN=1, NSLIP=0, ISURF=1,                    !5/30/01
 ISNOW= 1, ISAND=0,                             !snow (CRREL), no sand
 GAMMA=0.23, ZSNOW=19.7,                        !2/03/03  Alaska averages
 ZFREEZ=30, ZTHAW=0,
 MONTH= 1,                                      !vis season = 1st quarter
 RDFOG=300.0,                                    !max RDA driver variables
 COEFHD=1.0,                                    !max side slope
 REACT=.75,   DCLMAX=2.0,  SFTYPC=90.0,!braking
 VBRAKE= 2.0, VISMNV= 2.0,                      !min vis-limited speeds
 VWALK=  4.0,                                   !min veg-override speed
 VLIM= 100.0,                                   !max on-road speed
 $END
```

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